# UNTANGLING THE PROBLEM OF ABANDONED, LOST, AND DISCARDED FISHING GEAR: EVALUATING THE BENEFITS OF SIDE SCAN SONAR AS A GEAR DETECTION METHOD

By

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# Abstract

Abandoned, lost, or otherwise discarded fishing gear (ALDFG) has surfaced as a significant conservation issue that continues to compromise the economic, social, and ecological aspects of the marine environment. To alleviate these concerns, methods of gear detection can be applied to increase the precision of derelict gear retrieval and potentially improve the likelihood of success. Targeted in Canada's most productive American lobster (*Homarus americanus*) fishing area, 27 side scan sonar (SSS) transects were conducted in LFA 34 over a 12-day survey period in Clark’s Harbour, Nova Scotia, to evaluate the benefits of gear detection in large-scale retrieval missions. By conducting spatial analysis, results show that a hotspot of reported gear losses is strong in Clark’s Harbour. Following a comprehensive review of the SSS data, 114 potential ALDFG contacts were visually identified, and only one item was confirmed retrieved. Despite this, a large volume of ALDFG was retrieved in areas where there was no SSS coverage based on fisher’s local knowledge. This finding indicates retrieval efforts without the use of SSS can yield a high rate of ALDFG removal success. While gear can be located using SSS, greater grappling precision and full coverage SSS surveys is recommended at smaller geographic scales, such as sensitive benthic areas. Organizations should consider the cost of SSS surveys versus retrieval missions based on fisher’s knowledge in future applications.

*Keywords:* American lobster; Southwest Nova Scotia; Clark’s Harbour; ghost gear; ALDFG; gear detection; side scan sonar; gear retrieval missions; geospatial analysis; cost-benefit analysis; fisheries management.

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# List of Abbreviations

| | |
|---|---|
| AIS | Automatic Identification System |
| ALDFG | Abandoned, lost, or otherwise discarded fishing gear |
| BNAM | Bedford Institute of Oceanography North Atlantic Model |
| COSEWIC | Committee on the Status of Endangered Wildlife in Canada |
| DFO | Fisheries and Oceans Canada |
| FAO | Food and Agriculture Organization of the United Nations |
| GEBCO | General Bathymetric Chart of the Oceans |
| LFA | Lobster fishing area |
| SCUBA | Self-Contained Underwater Breathing Apparatus |
| SSS | Side scan sonar |
| SWNS | Southwest Nova Scotia |
| TVG | Time varying gain |
| UNEP | United Nations Environment Programme |

# Chapter 1.0 Introduction

## 1.1 Abandoned, lost, or otherwise discarded fishing gear (ALDFG)

Over the last decade, marine debris has surfaced as a global conservation issue (FAO, 2020), generating considerable mortalities amongst different marine species (Farias et al., 2018), reducing benthic biodiversity (Richardson et al., 2019), altering seabed characteristics (Kane & Clare, 2019), and negatively affecting the overall health of marine ecosystems (UNEP, 2014). Human activities place immense pressure on natural environments generated through industry and pollution of various sorts (Brown et al., 2011). While multiple studies have identified that land-based activities contribute to 80 to 90 percent of marine debris (Ambrose, et al., 2019), the rapid influx from the fishing industry has significantly contributed to the global problem (FAO, 2020; Gilman, 2015). Abandoned, lost, or otherwise discarded fishing gear (ALDFG) represents fishing related debris disposed either accidentally or deliberately into the marine environment (Gilman, 2015; Goodman et al., 2020; Richardson et al., 2019). While attempts to quantify the amount of ALDFG in the ocean estimate that ALDFG represents less than 10 percent of global marine litter by volume (Macfadyen et al., 2009), there is evidence that the problem may be even more prevalent in specific geographic locations (Gilman, 2015). Regions where there is presence of high-density fishing activity can yield to even larger quantities of fishing-related debris (NOAA, 2015).

Understanding the causes of lost gear presents a significant challenge, as gear loss is often unrecorded or not observed (Gilman, 2015). Researchers are proactively trying to understand the causes of lost gear. Of those, Richardson et al. (2021) interviewed 451 fishers from seven countries, where poor weather was a primary cause of lost gear. However, the study also shed light that a variety of causes emphasize the complexities of preventative methods. Previous studies have suggested that gear conflicts with other fishers (Goodman et al., 2019), improper disposal (NOAA, 2015), wildlife entanglement (Richardson et al., 2019), lack of fishing experience (Al-Masroori et al., 2009), and vessel interactions (Macmullen et al., 2004) directly impact the quantity of lost gear at sea. The site where derelict gear is found is also not necessarily indicative of where fishing gear was lost (Brown & Niedzwecki, 2020). ALDFG can travel far distances from their source location before sinking and accumulating on the seafloor or appearing on shorelines, and the distances to which ALDFG can travel through the marine environment are largely dependent on the strength of winds and ocean currents and the type of gear (Richardson et al., 2019). The adverse effects of ALDFG circulating in the water column can become a navigational hazard, both for vessels and marine mammals, as well as compromise the economic prosperity of fisheries (Gilman, 2015; Macfadyen et al., 2009; Richardson et al., 2019).

## 1.2 Ecosystem Impacts

As derelict fishing gear travels through the marine environment, ALDFG can continue to catch threatened or commercially important fish species (Goodman et al., 2021). This process, also known as ‘ghost fishing’, negatively impacts marine species causing entanglement or ingestion, resulting in a loss of ecosystem value (FAO, 2020). For example, tangled trawl nets, lobster trap snarls, polypropylene rope and monofilament lines can continue to catch species for several years after loss (Gregory, 2009; Long et al., 2014). Goodman et al. (2021) assessed by-catch from retrieved ALDFG and suggested that when species are caught or entangled by ALDFG, the cyclical process of self-baiting occurs. Of the 246 by-catch animals released from the baseline study, five out of the 15 species released from ALDFG were listed as species-at-risk by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Further, results indicated that derelict gear caught species at risk. Outside of bycatch, many marine mammals, such as sea turtles, pinnipeds, and cetaceans, are also subject to entanglement from ALDFG (Brown & Niedzwecki, 2020; Gregory, 2009). Often, escape from entanglement in gear is not possible for marine mammals, resulting in extensive injuries, starvation, and possible death (Gregory, 2009; Stelfox et al., 2016). Injury from fishing gear may also impact their ability to reproduce and feed (Saez et al., 2021).

Ocean currents can result in the movement of ALDFG, which can cause damage to benthic habitats and loss of ecosystem services (Guillory et al., 2001). Dynamic conditions can further demobilize ALDFG, causing physical abrasion to the seafloor substrate (Macfadyen et al., 2009). When derelict gear eventually settles, accumulation of gear can also smother benthic habitats and negatively impact biota (Guillory et al., 2001; Lewis et al., 2009). Lost gear embedded in soft or lying on hard benthic substrates may act as habitat for some species and cause further disturbances should gear be removed (Macfadyen et al., 2009). However, recent studies argue that removal of ALDFG provides greater long-term ecosystem benefits than leaving the ALDFG in place (Goodman et al., 2021).

## 1.3 Economic Impacts in the Canadian Context

Since the 1970's, research has been pursued to understand the sources, amount, lifespan, distribution and impacts of ALDFG (Richardson et al., 2019). With the increasing export-driven goals of marine fisheries, the quantity of derelict gear in the ocean is only expected to grow (FAO, 2020). ALDFG may cause direct or indirect impacts to the marine environment while also causing economic impacts to the industry due to losses in commercial fish stocks (Goodman et al., 2021; Morishige & McElwee, 2012). In Virginia, Scheld et al. (2021) suggest that removal of ~15-40 percent of lost gear annually would yield an increase of US ~3 million dollars in blue crab fisheries. Within the Canadian context, commercial landings and marine fisheries were valued at 3.6 billion in 2019 (Dawe et al., 2020), with the lobster fishery as the most profitable sector in the Canadian fishing industry, valued at 1.6 billion (DFO, 2019). Southwest Nova Scotia (SWNS) is considered the most productive American lobster (*Homarus americanus*) fishing area in Canada. An upward trend in lobster markets has been observed within the 45 directed fisheries, with the cause of this upward trend in productivity linked to distribution shifts of American Lobster populations from warming surface waters in the summer months along the Atlantic coast of North America (Bernier et al., 2018). Many rural communities across Atlantic Canada rely on the fishing industry for their livelihood (Greenan et al., 2019), which may be impacted due to ALDFG. Goodman et al. (2021) assessed the baseline impacts of ALDFG in SWNS, resulting in an estimated annual commercial loss of target species between $82,000 to $172,000 through the impacts of ghost fishing from ALDFG. Little research has been conducted to understand the adverse effects of ALDFG on commercial fishing markets and the marine environments in Canada. However, from the available published research and local evidence, ghost gear is a serious problem. While many coastal areas are struggling to effectively manage the issue (Scheld et al., 2021), innovative strategies for remediation will only further the success of monitoring and alleviating the effects of ALDFG (Gilman, 2015).

# Chapter 2.0 Remediation Strategies

## 2.1 Governing Regulations

Abandoned, lost, and discarded fishing gear management has been noted to be strongly tied to environmental, legislative, or behavioural pressures (Richardson et al., 2021). Calls to action to address the issue of ALDFG have been acknowledged in international and national mitigation initiatives (Angelini et al., 2019). In 2009, the Food and Agriculture Organization of the United Nations (FAO) and the Regional Seas Programme of the United Nations Environment Program (UNEP) spearheaded a study to raise awareness concerning the impacts of ALDFG and recommended mitigative actions (Macfadyen et al., 2009). Since publication, various governing bodies have initiated preventative and remedial programs (Gilman, 2015). Gilman (2015) assessed the efforts of 19 intergovernmental organizations, which highlighted weaknesses in derelict gear remediation, and emphasized the need for stronger reporting systems, data standards, and immediate retrieval programs.

Within Canada, recent changes in Conditions of Licenses managed by Fisheries and Oceans Canada (DFO) now require lost and retrieved gear reporting in all groundfish and shrimp fisheries (DFO, 2020). Before this change, DFO conservation and protection officers only recorded tag replacement information to monitor fishing effort (Goodman et al., 2019). Few intergovernmental bodies have adopted requirements to vessels for removal of lost gear (FAO, 2016); however, in Nova Scotia, fishers are at risk of lobster fishing license expulsion should they be caught with gear that is not theirs (Goodman et al., 2019). Government funded programs that enhance prevention and mitigation strategies are being introduced to support innovative solutions to reducing the issue of ghost gear. Such programs, for example, the Sustainable Fisheries Solutions & Retrieval Support Contribution Program (otherwise known as the Ghost Gear Fund), have been initiated by DFO to support projects related to “retrieval and disposal of ghost gear, investment in innovative gear technology, and encourage international leadership” (DFO, 2020). Without funding, efforts to prevent and mitigate ghost gear would be significantly reduced due to the high costs of retrieval and recycling (Global Ghost Gear Initiative, 2021).

## 2.2 Factors Influencing Retrieval Success

While abandoned, lost, and discarded fishing gear may be reported, significant challenges still exist in retrieving derelict gear (Goodman et al., 2019). In recent years, technology has advanced the longevity of fishing gear, propelling fishers to switch from traditional materials to synthetic products (Macfadyen et al., 2009). Fishing gear made from materials such as nylon, polyethylene, and polypropylene can withstand dynamic conditions at sea without degrading its effectiveness to catch (Stelfox et al., 2016). In Nova Scotia, a combination of wood, wire, or wood and wire traps are primarily used in lobster fisheries. In contrast, fixed or mobile gear for finfish and ground fisheries are predominantly longline or gillnets and trawls (Dawe et al., 2020).

The buoyancy of the fishing gear plays a critical role in ALDFG retrieval missions. Nets, hooks and lines, and pots and traps can perform differently under different environmental conditions. The weight, size and buoyancy of the material can affect how far gear may travel and increase the duration over which the gear continues ghost fishing. Lewis et al. (2009) highlighted that bathymetry may be a contributing factor to both trap placement and loss. The depth at which different types of ALDFG may travel can also vary depending on the level of biofouling that has built up on the gear (Stelfox et al., 2016). Biofouling is the process in which marine organisms attach and grow on the surface of ALDFG, usually observed following a lengthy period in the water (Stelfox et al., 2016). The added weight of the biofouling organisms can influence the buoyancy of the ALDFG in the water column until it eventually reaches the bottom. Typically, the gear ultimately sinks, but it may also snarl onto active gear, lost gear, or bycatch as it travels to the seafloor.

The differences between the type of lost gear and the environment in which it was lost heavily influence retrieval mechanics. Retrieval missions to obtain gear from the benthic zone will differ from those focusing efforts in the pelagic zone. The risk of conducting large-scale retrieval missions in the pelagic zone includes capturing marine species, further contributing to by-catch totals. Fishing gear used in the pelagic zone includes gillnets, which comprise a single wall of netting to catch target species, which threaten marine life when lost (Global Ghost Gear Initiative, 2021). When gillnet retrieval missions occur in deep-water fisheries, methods to retrieve gear involve using three grapples chained to a steel bar to hook onto the gillnets (Large et al., 2009; FAO, 2016). Once a gillnet is hooked onto the grapple, and depending on the size of the net, the gear can continue to fish non-target species as it is hauled onto the boat. Bottom towing with grapples is one of many ways to retrieve lost gear from the seafloor (Fundy North Fisherman's Association, 2016). This method is typically introduced following the closure of the seasonal fishery. During bottom towing retrieval missions, grapples are typically used to hook ghost gear at the seafloor, which can then be hauled to the surface. There are many designs of grapples (Global Ghost Gear Initiative, 2021), and they can be modified depending on the known bottom types over which they are used (Fundy North Fisherman's Association, 2016). For example, a span drag can be easily towed across a muddy or sandy bottom, while a cylinder-like grapple is more desirable for moving in between rocks and hard bottom (Figure 1).

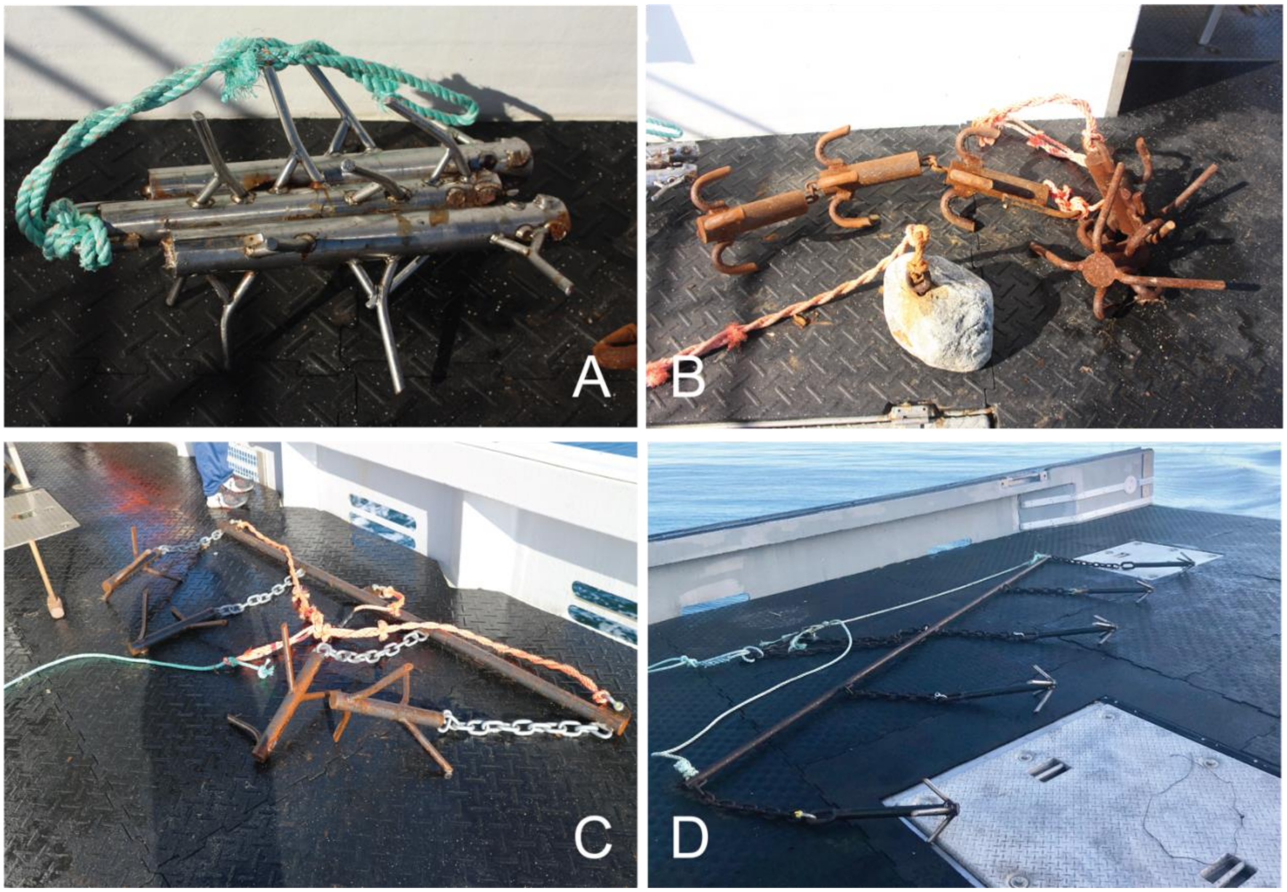


*Figure 1: Examples of grapples used for retrieval. Cylinder grapple attachments for retrieving gear between rocks and hard bottom types (A, B). Cylinder grapple attachment secured to span drag (C). Span drag configured with grapple anchors (D). Photos obtained from Coastal Action.*

Removing gear from the benthic environments can present concerns related to interactions with at-risk species, sensitive habitats, high cost, and safety. The heavy and large hooks used during retrieval missions may adversely affect the bottom habitat and cause seabed disturbance. Chartering fishing vessels, wages for captains and crew, fuel, and proper recycling of derelict gear can cost millions of dollars (Cho, 2011; Morishige & McElwee, 2012). Without government funded retrieval programs and incentives, removing ALDFG would unlikely be undertaken by industry due to the associated costs. To alleviate these concerns, methods of gear detection can be applied to increase the precision of retrieval activities, and potentially improve the likelihood of success.

## 2.3 Gear Detection

Gear detection is introduced as a method to pre-determine locations of abandoned, lost, or discarded fishing gear to facilitate retrieval of ALDFG. There is a strong emphasis on exploring gear detection methods and their performance across various seafloor habitats to facilitate the removal efforts of ALDFG. Implementation of detection methods can aid in "managing resources effectively, protect ecologically important areas, and set legislation to safeguard the oceans" (Brown et al., 2011, p. 502). Various approaches exist for lost gear detection and monitoring, ranging from manual efforts, such as SCUBA diving missions (Arthur et al., 2014), to automated underwater vehicles (Yu et al., 2020). Of the detection methods used in published research, acoustic instruments, such as side scan sonar, are increasingly being used in underwater detection as it yields distinctive results pertaining to objects that are visible on the seafloor (Arthur et al., 2014; Hamouda et al., 2021).

## 2.4 Application of Side Scan Sonar

In 2017, the Global Ghost Gear Initiative released "*Methods to Locate Derelict Fishing Gear in Marine Waters"* which highlighted side scan sonar (SSS) surveys as the primary tool for gear detection of ALDFG. Side scan sonar systems record acoustic data from a swath of seafloor to produce an image pertaining to the surficial seabed characteristics. Side scan sonar instruments can be mounted on a tethered towfish and towed behind a vessel (Plets et al., 2013), or mounted on remotely operated vehicles (Arthur et al., 2014). In the towed configuration, side scan sonar can be difficult to operate in highly variable or steep bottom environments (Arthur et al., 2014). Varying operating frequencies and transducer configurations can be manipulated to assess various seafloor substrate types and influence levels of success for object detection (Borrelli et al., 2018). Each transducer emits a fan-shaped acoustic pulse from the port and starboard side of the platform and records the returning signal (echo) as the platform moves along a survey track (Plets et al., 2013) (Figure 2).

Increasingly, dual-frequency side-scan sonar systems are being used in marine monitoring and exploration missions. These sensors typically operate at two discrete frequencies, providing different coverage and resolutions (Brown et al., 2011). The frequency of the pulses emitted varies depending on the desired range and the specifics of the system. Effective identification of marine debris on the seafloor using a side scan sonar is also dependent on weather conditions, noise, equipment quality, and post-processing software (Arthur et al., 2014; Black Laser Learning, 2018). Ultimately, the acquisition and interpretation of acoustic data are considered a key component to facilitating successful retrieval efforts of ALDFG (Borrelli et al., 2018).

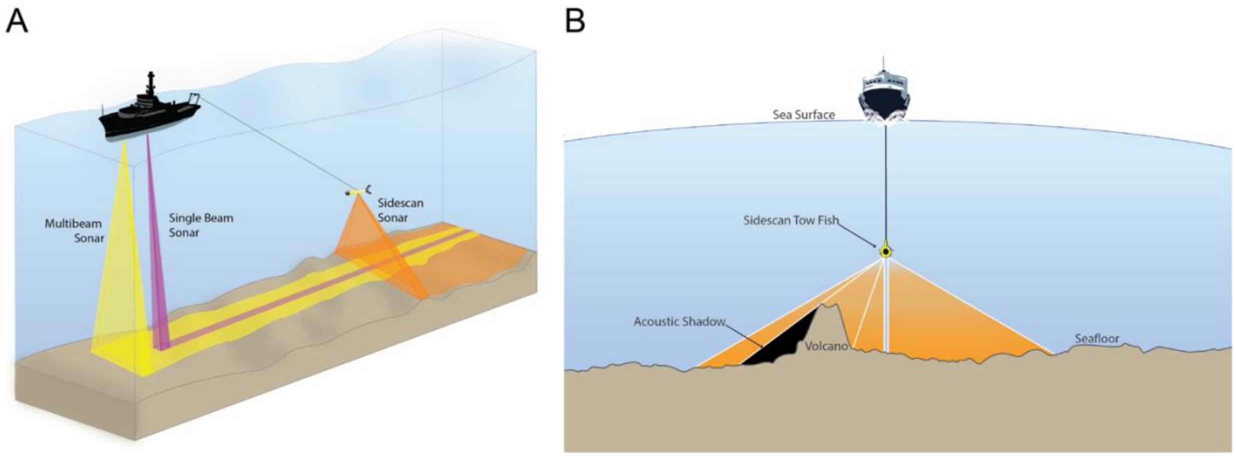


*Figure 2: A) Graphical illustration of the differences between multi-beam, single beam, and side scan sonar. B) Graphical illustration of the side scan towfish swath coverage of the seafloor. Illustrations by Vicki Gazzola.*

While international initiatives promote the applicability of side scan sonar as a gear detection method (Global Ghost Gear Initiative, 2021), limited published research is available pertaining to the detection of ALDFG and how this affects the subsequent success of retrieval operations. However, the value of side scan sonar has been demonstrated in target detection of underwater archeological sites (Chen et al., 2021; Ferentinos et al., 2020), forensic identification (Schultz et al., 2013; Ruffell et al., 2017), location and assessment of pipelines (Tian, 2008), assessing fishing impacts at the seafloor in protected areas (Demestre et al., 2015), and many other applications.  These studies demonstrate the ability of side scan sonar for target detection at the seabed. However, the use of side scan sonar for ALDFG detection is limited with respect to search timelines: Side-scan sonar surveys must be performed outside of fishing seasons as there is high risk of towfish entanglement with active gear. Additionally, there may be difficulty differentiating between active and lost gear imaged by the side scan system. These complexities associated with identification of ALDFG on the seafloor highlight the need to address the management problem in a local context.

## 2.5 Management Problem

The overarching goal of this study is to investigate the spatial distributions of ALDFG in Southwest Nova Scotia and evaluate the effectiveness of side-scan sonar in detecting lost fishing gear for large-scale retrieval missions. Specific objectives for the study were to:

1) Compile geospatial records of lost and retrieved ALDFG.
2) Conduct SSS surveys to determine the benefits and limitations of using these mapping technologies for detection and retrieval of ALDFG.
3) Identify other geospatial environmental data sets that are relevant in conducting gear detection and retrieval missions.
4) Provide recommendations on ALDFG gear detection and retrieval mission approaches.

# Chapter 3.0 Site Selection

Clark’s Harbour is located in Southwestern Nova Scotia (SWNS), approximately 260km west of Halifax and 90km east of Yarmouth. The town of Clark’s Harbour is located on Cape Sable Island within the Municipality of the District of Barrington in Shelburne County. Marine fisheries dominate the workforce in Clark’s Harbour. The harbour is located within the boundaries of lobster fishing area (LFA) 34 (Figure 3, Appendix A), which operate a seven-month fishing season, from November 28th to May 31st (DFO, 2019).

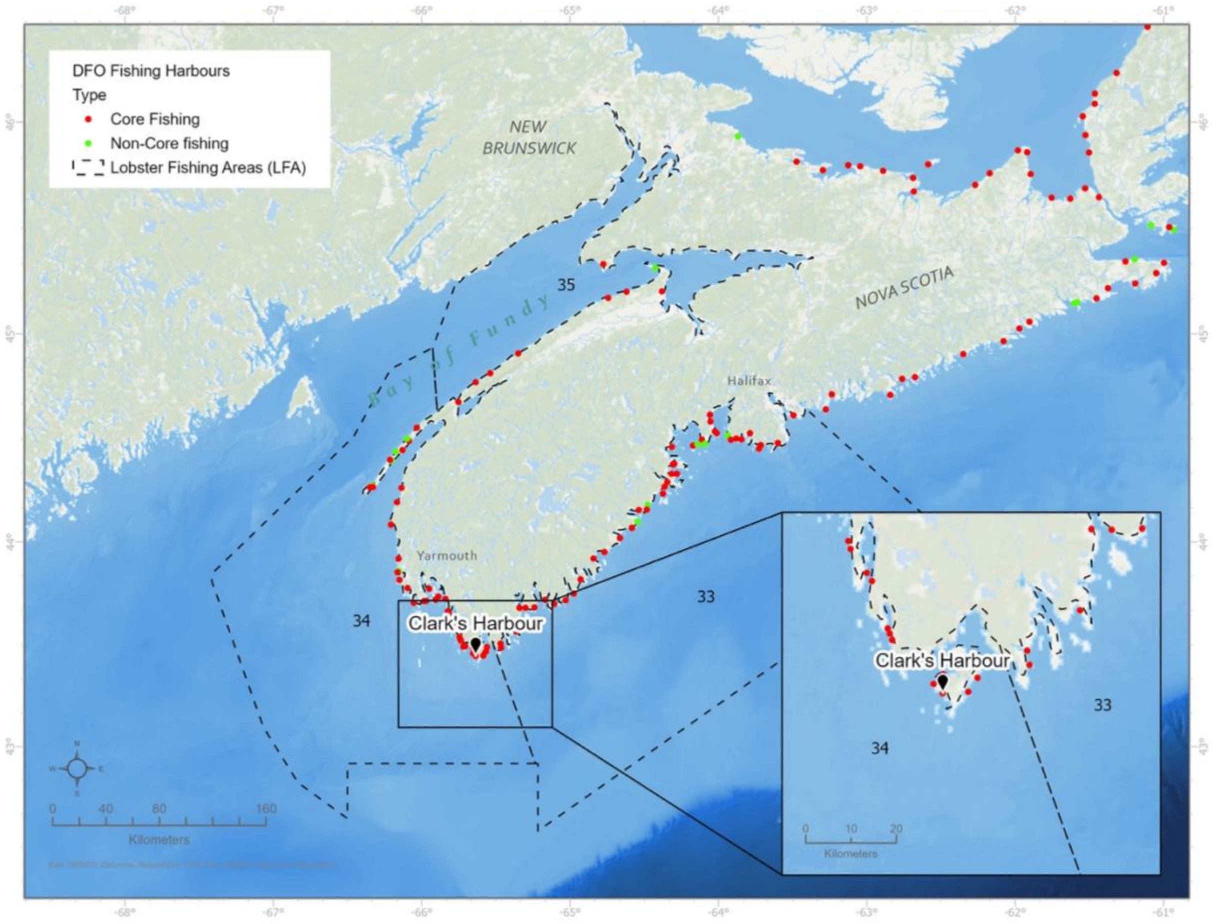


*Figure 3: DFO core and non-core fishing harbours in lobster fishing area (LFA) 33, 34, and 35. Inset map represents the location of Clark’s Harbour within LFA 34, and proximity to LFA 33.*

Near Clark’s Harbour exists the boundary of LFA 33, which operates during the same fishing season as LFA 34 (DFO, 2019). Combined, LFA 33 and 34 are considered the largest lobster fishing area in Nova Scotia, occupying nearly 1670 lobster fishing licenses (DFO, 2019) (Table 1). As a result, they generate the most significant amount of ALDFG (Dawe et al., 2020).

*Table 1: Number of lobster fishing licenses and total allowable traps per lobster fishing area.*

| Lobster Fishing Area (LFA) | Season | Number of Fishing Licenses | Number of Allowable Traps | Total Allowable Traps per LFA |
|---|---|---|---|---|
| LFA 33 | Last Monday of November – May 31st | 683 | 250 | 170.750 |
| LFA 34 | Last Monday of November – May 31st | 979 | 400 | 391,600 |

## 3.1 Fishing Pressures

As Southwest Nova Scotia represents the most dominant American Lobster fishery in Canada, fishing activity was explored further in the geographic context of Clark's Harbour. By obtaining open-source data, fisheries landings and effort of inshore lobster fishing was mapped using the Maritimes region statistical grid (Coffen-Smout et al., 2013). The findings indicated that LFA 34 represents the highest catchweight, the highest number of license-days fished, and trap hauls between 2012-2014 (Serdynska & Coffen-Smout, 2017). The maps generated from the data illustrate that a high-density distribution of lobster traps per km$^2$ encompasses a significant portion of LFA 34 (Figure 4, Appendix A).

Further in-depth analysis of each grid cell (Figure 4) revealed that the designated cell that surrounds the Clark's Harbour region represents the highest number of traps per km$^2$ in Nova Scotia, totalling approximately 13,771 traps per km$^2$ during the 2012-2014 period (Table 2). Year-to-year differences in fishery activity may change because of economic or climate change impacts, however, published literature regarding fishing pressures in the region is limited. Given a nearly 5,000 tonnes increase in lobster landings in LFA 34 from 2014 to 2016, the values detailed in Table 2 are only expected to increase. While these statistics are time-sensitive, the data provides insight into the fishery distribution at course scale. Since the publication of the research by Serdynska and Coffen-Smout (2017), fishing activity maps in Nova Scotia have not been produced and publicly shared, resulting in a limited knowledge transfer when targeting lost gear retrieval efforts. Although adopting a region-wide coordinate reporting system of lobster landings and effort would contribute to decision-making responses to ALDFG, a shift in government management along with discussions with industry will be required to address confidentiality requirements.

*Table 2: Lobster landings and fishing effort statistics from 2012-2014 of grid number 158 surrounding Clark's Harbour.*

| Area ($km^2$) | Weight (kg) | Traps Hauled | Days Fished | Trap Weight (kg) | Trap Weight per $km^2$ | Traps per $km^2$ | Days Fished per $km^2$ |
|---|---|---|---|---|---|---|---|
| 243.41 | 3,131,899.34 | 3,352,233 | 11,101 | 0.94 | 12,866.51 | 13,771.7 | 45.6 |

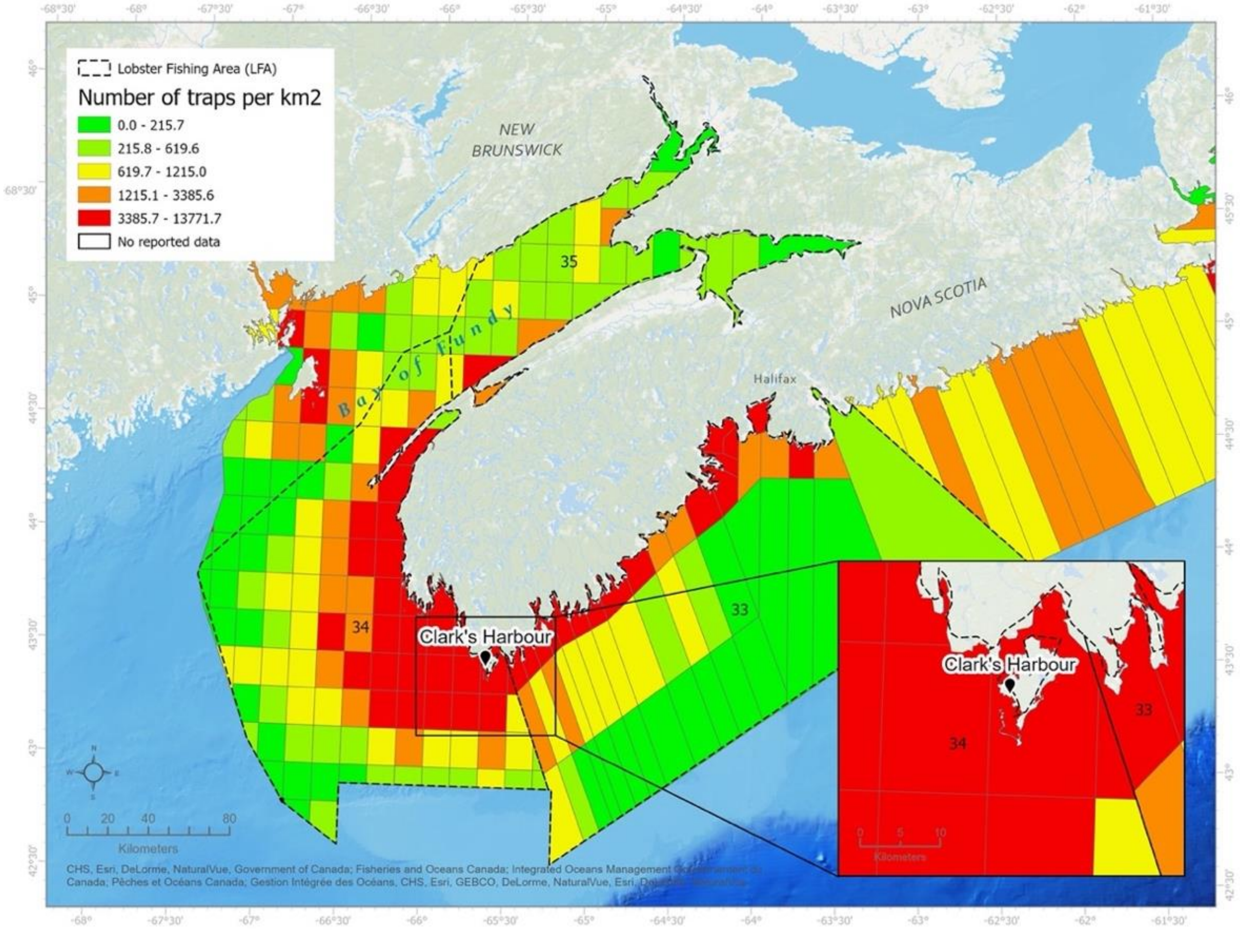


*Figure 4: Number of lobster traps per km2. Data retrieved from DFO.*

## 3.2 Reported Lost Fishing Gear

Since 2020, DFO has mandated reporting of lost and retrieved fishing gear in all Canadian commercial fisheries (DFO, 2020). The information is used to understand lost gear distribution patterns and quantify the amount of ALDFG in Canadian waters. The management initiative is used to coordinate short-term and long-term measures to address the issue of ALDFG in Canada (DFO, 2020). To further understand the spatial distribution of lost fishing gear in

SWNS, reported lost gr data was obtained from DFO and represented spatially based on lost gear coordinates (Figure 5, Appendix A). The spatial distribution of reported lost fishing gear indicated a high distribution of losses inshore of Pubnico and Clark's Harbour. More specifically, the reported lost gear (Figure 5) spatially aligns with the areas of observed high fishing pressure (Figure 4). However, it should be noted that the two datasets do not span the same period. Nonetheless, given this correlation, it can be understood that Clark's Harbour represents a significant area of interest for presence of ALDFG. These datasets presented above will be used to define the survey areas for ALDFG detection using SSS.

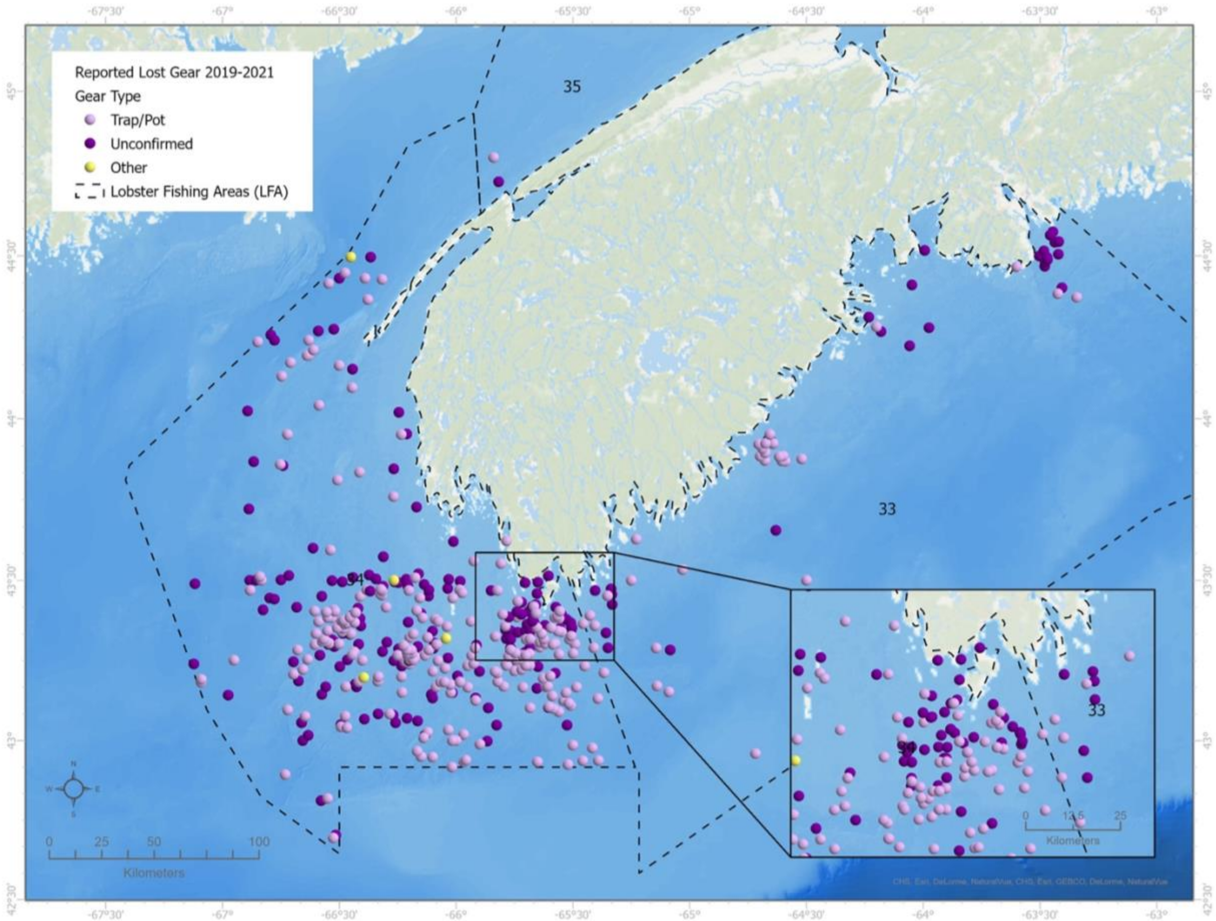


*Figure 5: DFO reported lost fishing gear data from 2019 to June 2021. Data obtained from Fisheries and Oceans Canada (2017).*

# Chapter 4.0 Methods

A comprehensive review of the literature revealed only one published research report that evaluated the accuracy of lost gear detection of side scan sonar surveys (Clark et al., 2012), revealing a significant knowledge gap in the use of this survey method for ALDGF detection (Chosid, 2017). This project was developed in coordination with the *Collaborative Remediation of Abandoned, Lost and Discarded Fishing Gear in Southwest Nova Scotia* led by Coastal Action, a non-for-profit environmental organization based out of Mahone Bay, Nova Scotia.

## 4.1 Compilation of Geospatial Data

The side scan survey design was developed using regional lobster fishing pressures, and locations of reported lost fishing gear collected by DFO (Figure 4, Figure 5). In addition, environmental parameters that influence gear distribution patterns were compiled and analyzed to infer relationships with gear movement. As such, bathymetry, annual surface ocean currents and annual bottom ocean currents were evaluated further.

### 4.1.1 Environmental Parameters

Seafloor bathymetry relates to the depth of the seafloor relative to sea level and can be used to generate digital elevation models that represent the topography of the seafloor environment (NOAA, 2021). Understanding lost gear distribution patterns related to bathymetry has been used in other studies to quantify the number of lost crab pots across different depth ranges (Bilkovic et al., 2014), gear movement patterns (Lewis, Slade, Maxwell, & Matthews, 2009), as well as to understand the correlation of depth and ALDFG bycatch (Masompour et al., 2018). Gridded bathymetric data was obtained from GEBCO and represents a global terrain model in meters on a 15 arc-second interval grid (GEBCO, 2021).

Surface winds and currents interact differently over various spatial and temporal scales (Bôas et al., 2019). Understanding ocean surface currents are vital for “ship routing, search and rescue efforts, biological and chemical studies, and both hindcasts and forecasts of the transport and dispersion of floating material including plastic and oil” (Lumpkin & Johnson, 2013, p. 2992). Abandoned, lost, or otherwise discarded fishing gear can travel significant distances from wind or surface currents before accumulating on shorelines or sinking to the ocean floor (Richardson et al., 2019). While there has been significant progress in developing surface current models over the years to comprehend the distribution of marine debris and the like, gaps still exist surrounding winds, currents, and waves modelling (Bôas et al., 2019). While surface currents capture the upper portion of marine environments, currents also flow across the ocean floor, which can vary in magnitude and direction from surface currents. Bottom currents are characterized by a variety of origins, flow directions and velocities (Shanmugam, 2008). Three different bottom currents are most prominent along the seafloor: wind-driven bottom currents, thermohaline bottom currents, and deep-water tidal currents (Shanmugam, 2008). These methods of transportation influence the rate of sedimentation (Rajput & Thakur, 2016), and the movement of debris that may have settled onto the bottom (Angiolillo & Fortibuoni, 2020).

Using open-source data obtained from Fisheries and Oceans Canada, monthly mean currents from the Bedford Institute of Oceanography North Atlantic Model (BNAM) results were obtained to gather information on distribution patterns of ALDFG based on the climatology for the Northwest Atlantic Ocean. These datasets were averaged from the 1990 to 2015 period, which are considered representations of the monthly climatological state of the Northwest Atlantic Ocean measured in m/s.

While the available data for ocean currents in the North Atlantic is represented at broad scales, the current speeds and directionality captures a snapshot of the patterns in lieu of the lack of fine scale data and models. For this analysis, monthly mean oceanographic current point data was interpolated using empirical Bayesian kriging to determine a mean annual current model. *Empirical Bayesian Kriging* is a geostatistical interpolation method used in ArcGIS Pro that automates the calculation of kriging model parameters by predicting the unknown point locations based on the known data locations (Esri, n.d.). Using the Raster Calculator, the values were then summed and divided by 12 to obtain an annual representation.

### 4.1.2 Reported Lost Gear Hotspots

The reported lost fishing gear locations representing lost gear up until June 2021 were obtained from Fisheries and Oceans Canada and were represented spatially by displaying their latitudinal (Y) and longitudinal (X) coordinates in Esri mapping software, ArcPro 2.7. Prior to determining the hotspots of lost gear, a Global Moran’s I spatial autocorrelation test was completed. The results of the Global Moran’s I test presents whether the data is spatially clustered based on the location and value of the dataset. Following the spatial autocorrelation test, an optimized hotspot analysis was completed using a custom grid structure (Figure 6) to confirm potential significant spatial clusters of high values (hotspots), low values (cold spots), and locations that were considered insignificant.

Hotspots were developed by an aggregation of reported lost gear using a 3km x 3km fishnet. The fishnet was produced using the geographic extent of the reported lost gear (Figure 6, Appendix B). The result of the analysis produced a hotspot map showing number of records per km$^2$. A hotspot can be characterized as an area with higher concentration of events compared to others through point distributions in space. The aggregation of points to zones identifies zones of high- or low-density gear losses. The use of bivariate colour symbology to the aggregated dataset was applied to highlight quantitative relationships between the number of reported gear losses and the number of units of gear loss. Highlighting this relationship through symbology can provide insight on areas where a high number of reports and a high number of pieces of gear are being lost within a 3km x 3km zone.

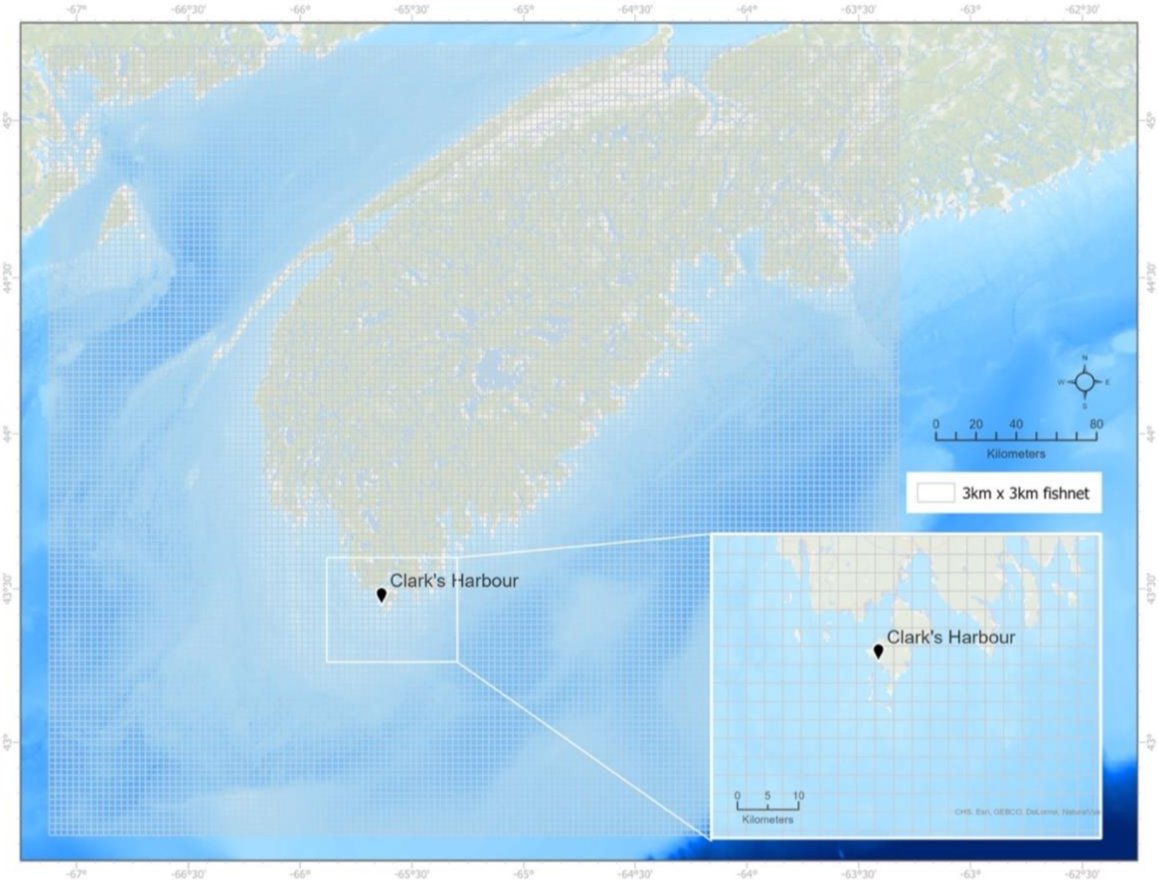


*Figure 6: A 3km x 3km fishnet was developed as aggregation zones based on the spatial extent of DFO reported lost gear records.*

In addition to the spatial analysis, fishers can provide valuable information for assessing spatial locations of ALDFG (Cho, 2011), and their input is considered essential to identify hotspot targets (Global Ghost Gear Initiative, 2021). Anonymous insight was collected by Coastal Action from local fishers and community members through an online survey, providing target search areas derived from local knowledge. Additionally, the coastline of Clark's Harbour, located in Southwest Nova Scotia, was selected based on the high-density of lost gear hotspots and the prevalent occurrence of lost gear appearing on coastal shores. Combined, this information in addition to the hotspot analysis was used to identify the side scan sonar survey locations.

## 4.2 Research Tools

Side scan sonar surveys were conducted using an EdgeTech 4205 MPMT Dual Frequency Sonar, operated at a low frequency of 230kHz and a high frequency of 850kHz. The low frequency signal covered a swath of seafloor at a width of 150m on each side of the side scan sonar towfish, while the high frequency sonar covered a swath of seafloor at a width of 50m on each side. The *MV Island Venture*, a 50-foot fishing vessel, was used for the surveys. Side-scan data corrections were applied post-acquisition using Chesapeake Technology SonarWiz 7. Correction applied to the raw side scan sonar data included auto time varying gain (TVG), which adjusts the acoustic signal strength relative to distance from the towfish to account for signal attenuation through the water column. Environmental parameters and fishing pressure data were compiled from various sources and assembled in ArcGIS Pro 2.7 (Table 3). File management of all geospatial data layers was recorded within an Esri geodatabase.

*Table 3: Geospatial data layers used to determine side scan sonar survey design.*

| Data Layer | Spatial Object Type | Data Model | Data Source |
|---|---|---|---|
| Bathymetry | Surface | Raster | GEBCO (2021) |
| FGP/Maritimes Inshore Lobster Landings Effort 2012-2014 | Polygon | Vector | Coffen-Smout et. al. (2013) |
| Lobster Fishing Areas (LFA) | Polygon | Vector | DFO (2020) |
| Monthly Mean Bottom Currents | Point | Vector | Wang, Z., Lu, Y., Greenan, B., Brickman, D., and DeTracey, B. (2018) |
| Monthly Mean Surface Currents | Point | Vector | Wang, Z., Lu, Y., Greenan, B., Brickman, D., and DeTracey, B. (2018) |
| Reported Lost Fishing Gear (LFA33, 34, 35) | Point | Vector | DFO (2021) |
| Retrieved Abandoned, Lost, or otherwise Discarded Fishing Gear | Point | Vector | Coastal Action (2021) |
| Small Craft Harbours | Point | Vector | DFO (2020) |

## 4.3 Acoustic Survey Design

Based on the results of the hotspot analysis (section 4.1 above), locations of reported ALDFG densities were identified to develop the side scan sonar survey design. As gear losses may be considered higher in particular cells, this survey design aimed to capture a multitude of gear loss densities to understand the bottom conditions at which gear is being reported. Using the 3km x 3km aggregation grid of DFO reported lost gear, 27 transect lines were placed through hotspot cells of varying ALDGF densities. The side scan sonar surveys were designed to cover 10 percent of the area within each of the targeted grid cells. Survey transects were categorized by nearshore, inshore, offshore transects (Table 4). Nearshore, inshore, and offshore categories were distinguished based on distance from the Clark's Harbour government wharf and designed to developed to collect data based on a range of hotspot densities. Lines 12, 13, 14 and 15 are not considered in this analysis as the transects were conducted over previously retrieved areas.

*Table 4: Side scan sonar survey transects detail and completion rate.*

| Survey Transect Number | Survey Type | Survey Distance (km) |
|---|---|---|
| Line 1 | Inshore | 13 |
| Line 2 | Inshore | 13 |
| Line 3 | Inshore | 11 |
| Line 4 | Inshore | 11 |
| Line 5 | Inshore | 11 |
| Line 6 | Nearshore | 7 |
| Line 7 | Nearshore | 19 |
| Line 8 | Nearshore | 7 |
| Line 9 | Nearshore | 11 |
| Line 10 | Nearshore | 7 |
| Line 11 | Nearshore | 7 |
| Line 16 | Offshore | 11 |
| Line 17 | Offshore | 11 |
| Line 18 | Offshore | 11 |
| Line 19 | Offshore | 11 |
| Line 20 | Offshore | 11 |
| Line 21 | Offshore | 11 |
| Line 22 | Offshore | 17 |
| Line 23 | Offshore | 11 |
| Line 24 | Offshore | 11 |
| Line 25 | Offshore | 15 |
| Line 26 | Offshore | 17 |
| Line 27 | Offshore | 17 |

## 4.4 Survey Data Acquisition and Calibration

Survey data acquisition was conducted by staff from Ocean Tracking Network (OTN) and Ocean Frontier Institute (OFI). Side scan sonar survey data collection was planned for 12 calendar days for data collection. Due to constraints that will be discussed later, 9 out of 12 days were completed. Survey data collection was conducted from June 14th, 2021, to June 22nd, 2021 (Table 5). The EdgeTech 4205 MPMT Dual Frequency Sonar was deployed from the stern of the vessel and maintained an altitude of 10-15 metres above the bottom along its navigational path and maintained survey speeds between 3-4 knots. Faster speeds would generate drag that would prevent the towfish from reaching the desired altitude above the bottom, whilst slower speeds would increase the susceptibility of experiencing effects on data quality from wave action or currents on the towfish (Chosid, 2017). During acquisition, the side scan sonar recorded the backscatter intensity from the seafloor and tracked the data in real-time.

*Table 5: Survey Transects Completed from June 14 to June 22, 2021.*

| Collection Day | Date | Survey Transects Completed |
|---|---|---|
| 1 | June 14, 2021 | Line 4, Line 5, Line 8 |
| 2 | June 15, 2021 | Line 1, Line 2, Line 6 |
| 3 | June 16, 2021 | Line 3, Line 7, Line 8, Line 9 |
| 4 | June 17, 2021 | Line 22, Line 23, Line 24, Line 5 |
| 5 | June 18, 2021 | Line 16, Line 17 |
| 6 | June 19, 2021 | Line 4, Line 7, Line 8 |
| 7 | June 20, 2021 | Line 20, Line 26, Line 27 |
| 8 | June 21, 2021 | Line 19, Line 20, Line 5, Line 7 |
| 9 | June 22, 2021 | Line 12, Line 14, Line 15 |

Weather and sea state conditions were recorded during survey data acquisition. Throughout the nine data of data collection, there was minimal wind and waves and only a light swell present in Clark’s Harbour (Table 6). Windspeed was highest during survey day #2, #3, #6 and #7, which reduced the data quality on those days.

*Table 6: Average weather conditions during data collection period recorded from Baccaro Point/ Clark's Harbour.*

| Collection Day | Date | Temperature (°C) | Relative Humidity | Precipitation (mm) | Wind Direction | Wind Speed (km/h) |
|---|---|---|---|---|---|---|
| 1 | June 14, 2021 | 11.77 | 88.46 | 0.00 | 128.42 | 9.36 |
| 2 | June 15, 2021 | 12.42 | 97.50 | 0.73 | 132.88 | 16.02 |
| 3 | June 16, 2021 | 12.90 | 93.29 | 0.38 | 227.00 | 14.34 |
| 4 | June 17, 2021 | 11.80 | 87.71 | 0.01 | 244.04 | 13.38 |
| 5 | June 18, 2021 | 11.88 | 85.67 | 0.00 | 216.54 | 12.46 |
| 6 | June 19, 2021 | 11.77 | 90.17 | 0.18 | 191.42 | 23.68 |
| 7 | June 20, 2021 | 12.40 | 90.96 | 0.00 | 249.04 | 17.57 |
| 8 | June 21, 2021 | 12.36 | 94.63 | 0.00 | 193.21 | 11.69 |
| 9 | June 22, 2021 | 13.57 | 96.79 | 0.20 | 179.79 | 13.54 |

## 4.5 ALDFG identification

Objects that were potentially ALDFG were visually identified from the processed side scan data. A preliminary scan of the geo-referenced images from the 25 transects was conducted immediately following the final day of data collection. Potential ALDFG targets from the side scan were identified and coordinates were extracted and distributed for retrieval. The preliminary scan of ALDFG contacts was completed to accommodate the beginning of ghost gear retrieval missions occurring three days after side scan sonar data was collection. Initial target identifications, raw side scan data, and processed side scan sonar transects were used to generate final identification targets. Initial targets are considered targets found following the surveys on data before post-processing, while final identification targets are characterized as targets following a second review to ensure they were correctly identified.

## 4.6 Retrieval Effort

Coastal Action organized and managed gear retrieval efforts in Clark’s Harbour as part of a large-scale retrieval mission in Southwest Nova Scotia. Gear retrieval was conducted by one captain over 15 retrieval days in the Clark Harbour region in LFA 34. Retrieval was conducted during low wind speeds and calm sea conditions. Grapples were towed behind the commercial fishing vessel, the *MV Once Upon a Tide,* at a speed of 0.5 to 3 knots. During the 15 days of retrieval trips, a total of 157 tows were completed. In place of Automatic Identification System

(AIS) tracking data from retrieval vessels, the towed distance was collected based on the distance between when the grapple was submerged into the water (IN coordinate), to when the grapple was hauled out of the water and the towing halted to a stop (OUT coordinate). The coordinates were then imported into ArcGIS Pro 2.5 using the Display XY tool. Once the IN and OUT coordinates were displayed respectively, the Merge tool was applied to combine the values based on the ObjectID field. An additional field, named ID, was then created that copied the values from the ObjectID field. Once completed, the Merged dataset was run through the Point to Line tool, where the newly created ID field filled the Line Field. As a result, lines were created from the IN to the OUT coordinates, representing the distance the grapple was submerged underwater. Tows varied in length depending on marine conditions. A variety of information was collected during retrieval missions to understand the state of gear retrieved, by-catch details, and spatial locations. Tows that did not retrieve any gear were considered “nil” tows.

# Chapter 5.0 Results

## 5.1 Geospatial Compilation of Environmental Parameters

### 5.1.1 Seafloor Bathymetry

The contour lines on Figure 7 show the bathymetry of Southwest Nova Scotia, and in particular, Clark's Harbour. Depths off the coast of Clark's Harbour are characterized by relatively shallow areas between 0m to 60m. As distance from Clark's Harbour increases, deeper basins to the east and west are apparent, exceeding depths greater than 370m. German Bank, located south from Clark's Harbour along the Scotian Shelf, ranged from 20m in depth east of German Bank, to up to 200m in depth in the westerly basins.

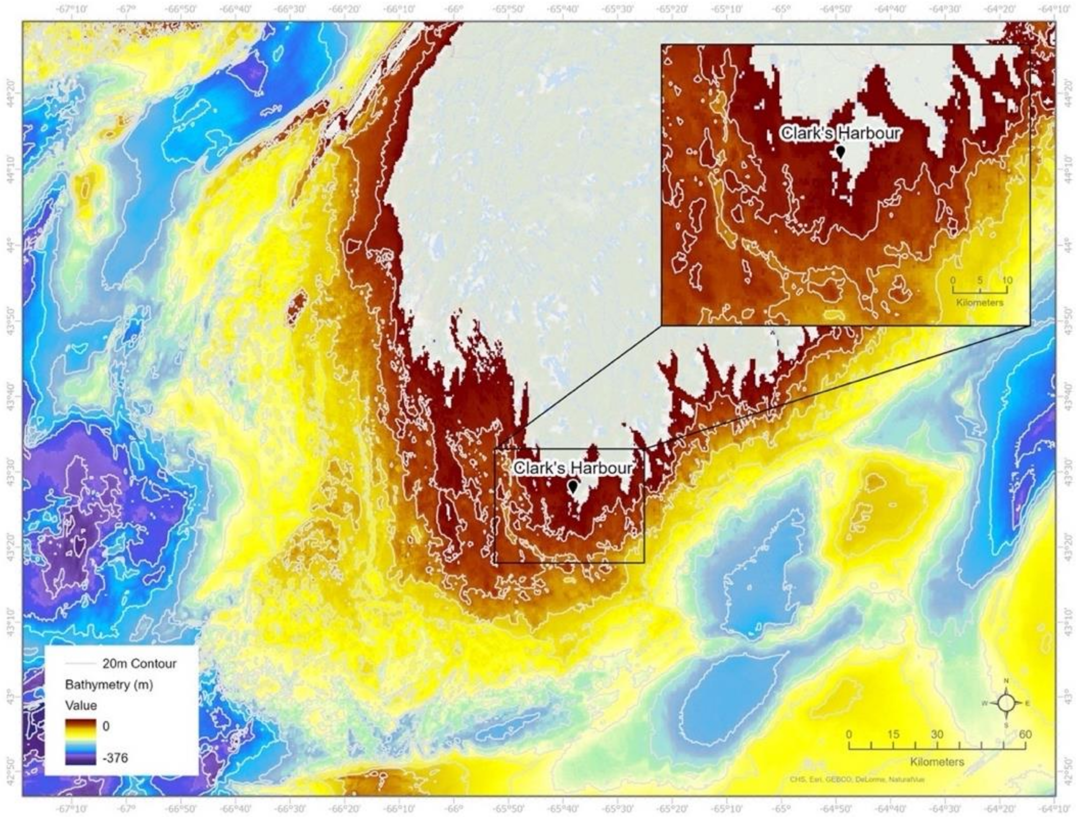


*Figure 7: Seafloor bathymetry of SWNS. The 20 m contour lines are displayed.*

Based on DFO reported lost gear and fishing effort data sets around southwest Nova Scotia (**Error! Reference source not found.**, **Error! Reference source not found.**, Appendix A), fishing activity predominantly occurs in areas less than 80 metres in depth. In the Clark's Harbour region, areas of particular interest are characterized by depths less than 40 metres (Figure 7, Appendix A). Seafloor habitats have not been mapped for this area, but environmental attributes such as bottom roughness from imagery, mean surface currents, and mean bottom currents may provide additional details in understanding lost and retrieved gear patterns along with the bathymetric data.

### 5.1.2 Annual Mean Ocean Currents

Ocean circulation patterns can influence gear movement, where surface currents and bottom currents can impact the rate at which gear moves. Lost gear may travel from high energy to low energy environments before eventually settling towards the bottom.

#### *Surface Currents*

Mean annual surface currents depict direction and speed, showcasing a varying current speeds and directionalities (Figure 8, Appendix C). The northwest flow coming from the Gulf of Maine flows across the German Shelf and onto the Scotian Shelf at low to moderate speeds. In depths less than 60m, surface currents flow towards to the northeast. Higher current speeds appear off the coast of Nova Scotia in depths greater than 60m, with flow directed towards the southwest. Surrounding Clark's Harbour, surface currents at lower speeds coming from the west converge at the base of Cape Sable Island, either flowing towards the northeast coast, or along the northwest coast of Southwest Nova Scotia.

#### *Bottom Currents*

A low magnitude Nova Scotian current is featured along the coast moves towards southwest Scotian Shelf (Figure 9, Appendix C). High speed dominates depths greater than 1000m, and flow in a south-southwesterly direction (Figure 9, Appendix C). The northwest flow coming from the Gulf of Maine towards German Bank and across the Scotian Shelf, exemplifying a clockwise pattern. Surrounding Clark's Harbour, bottom current directionality is characterized by southwesterly currents coming from the east, converging at the head of Clark's Harbour with southeasterly currents coming from the Gulf of Maine. While lower magnitudes are dispersed throughout the region, moderate speeds of bottom currents ranging between 0.10 and 0.50 m/s are prevalent surrounding Clark's Harbour and Lobster Bay.

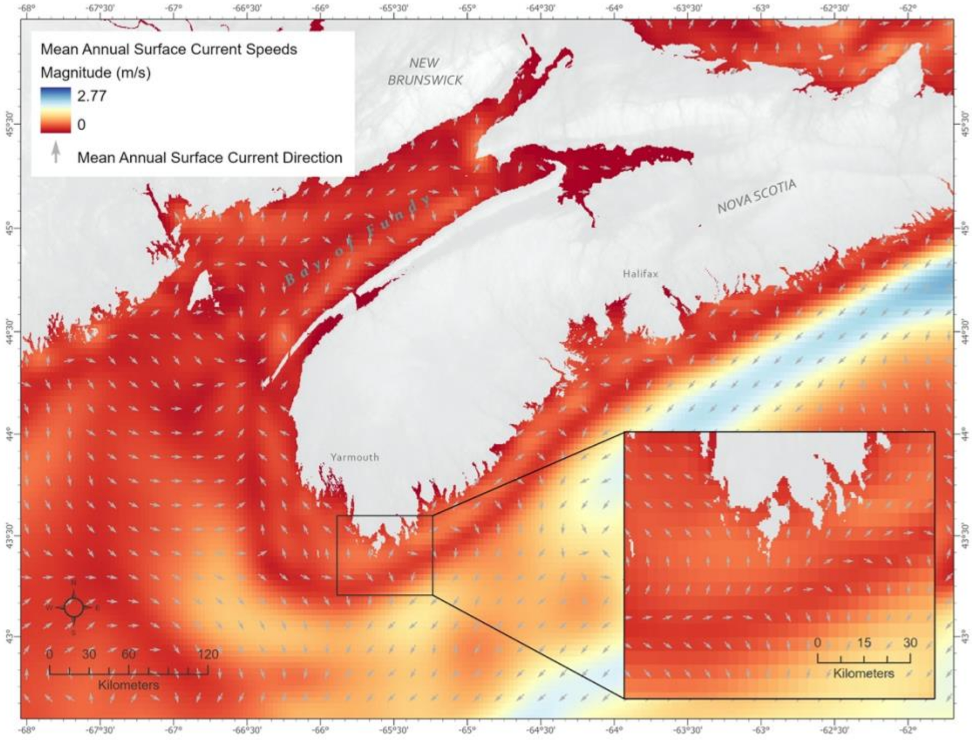


*Figure 8: Annual mean surface currents and directionality. Data obtained from Wang et al., (2018).*

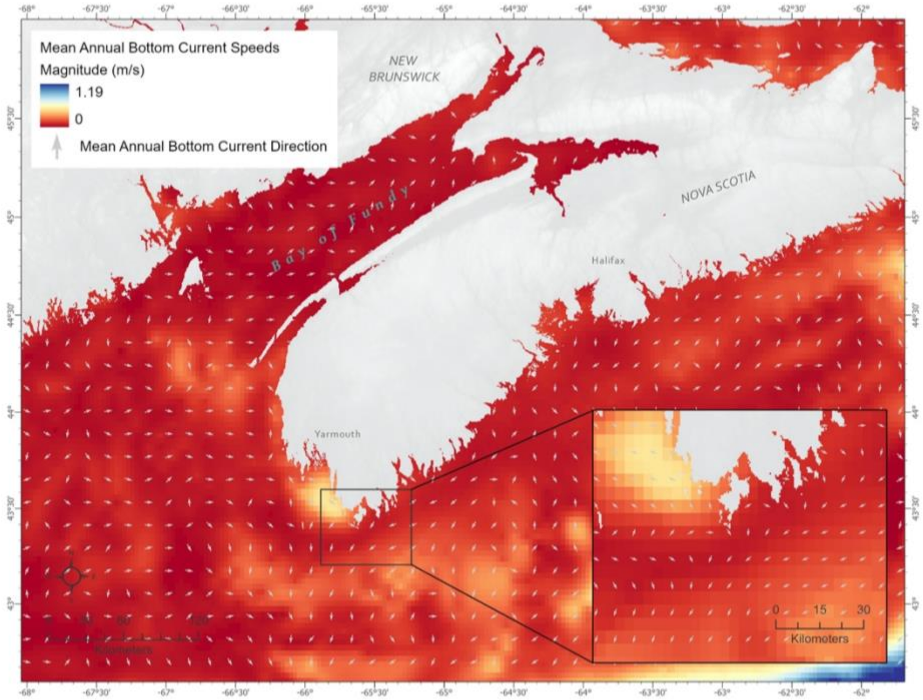


*Figure 9: Annual mean bottom currents and directionality. Data obtained from Wang et al., (2018).*

## 5.2 Hotspot Analysis

From the reported lost gear dataset aggregated to 3km x 3km zones (Figure 5, Figure 6), Global Moran's I spatial autocorrelation test revealed statistically significant spatial clustering with a z-value of 55.0195 and a p-value of 0.000. A low z-value indicates little to no clustering, while a high z -value indicates a stronger clustering intensity. A p-value of 0 reveals that the pattern of reported lost fishing is highly unlikely of a random process. Following a spatial autocorrelation test, the optimized hot spot analysis results revealed a statistically significant hot spot with 99 percent confidence off the coast of Clark's Harbour less than 80 m in depth (Figure 10, Appendix C). Based on the reported lost gear data, areas not statistically significant include locations off Digby Neck, Lunenburg, and areas more significant than 80 m offshore. The results of the hotspot analysis also yielded hotspots with 99 percent confidence near Seal Island. Hotspots with a 90 percent confidence revealed areas less than 60 m in depth off the coasts of Liverpool.

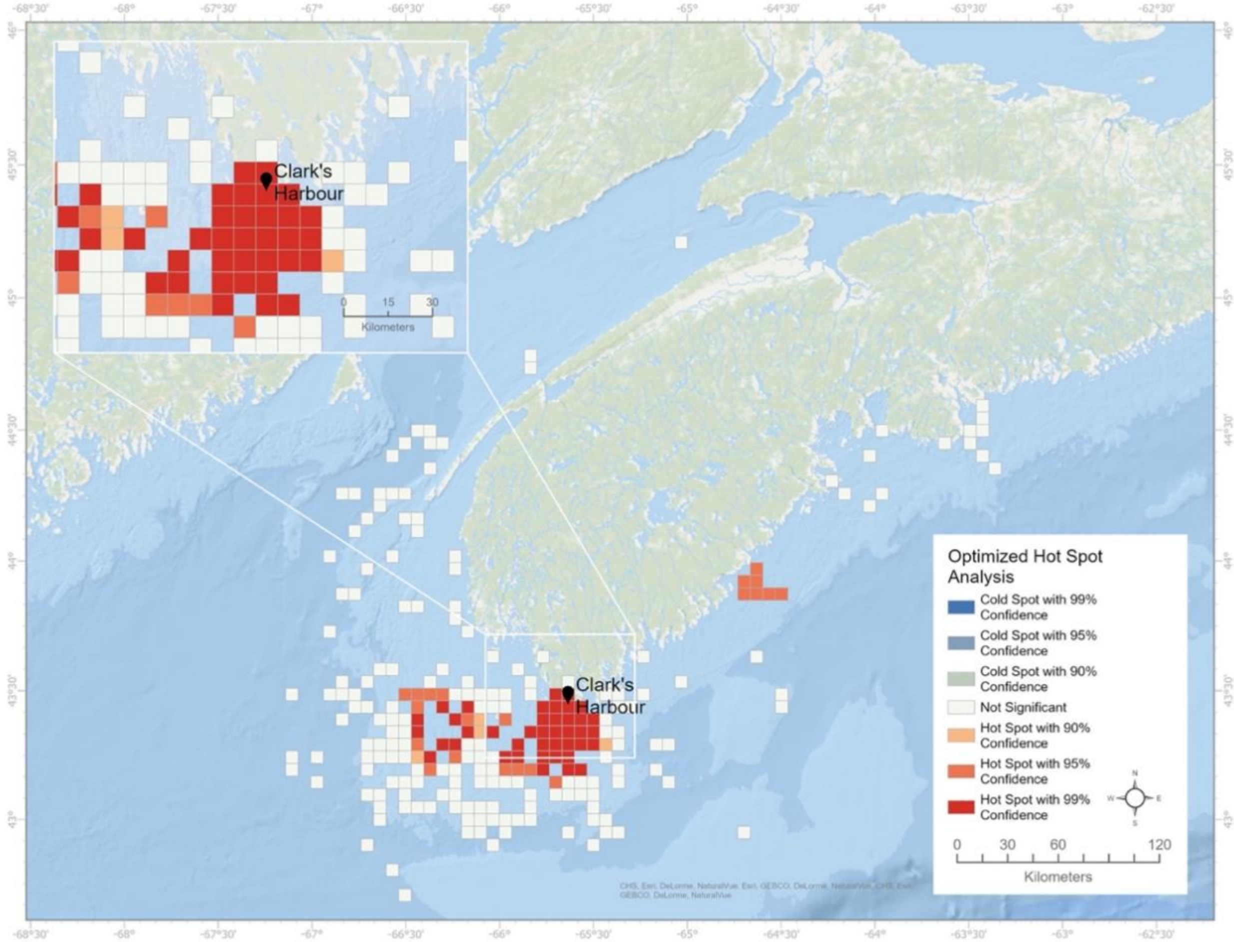


*Figure 10: Optimized Hot Spot Analysis of DFO reported gear losses.*

An area can be considered a hotspot when a higher-than-average occurrence of the reported lost gear is found in a cluster. As the number of reported gear losses increases over time, the data will strengthen the results of the hotspot analysis, which can then be used for targeted gear detection and retrieval.

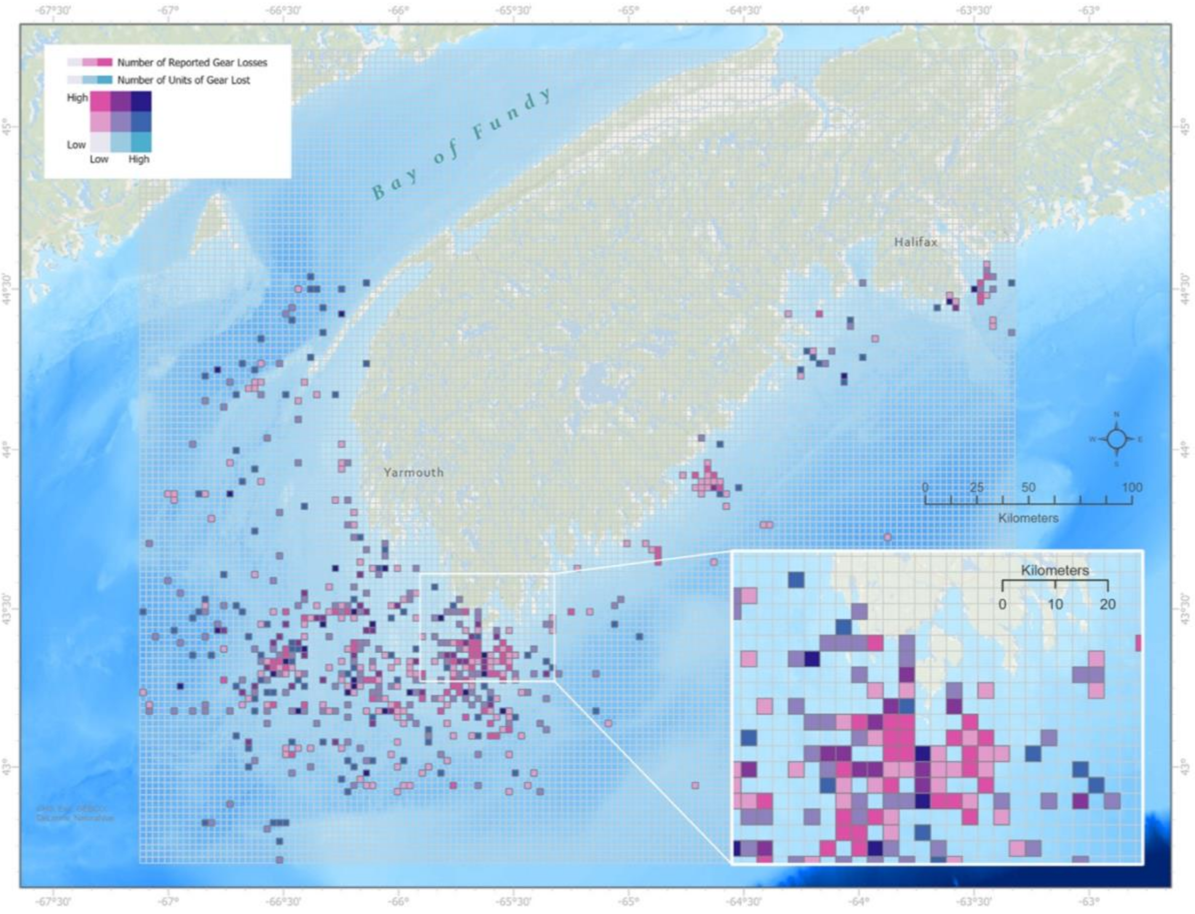


*Figure 11: Reported lost gear and number of units of gear loss in a 3km x 3km zones.*

Using a bivariate colour scheme, the distribution of reported gear losses and the number of units of gear lost revealed a relationship between the two variables (Figure 11, Figure 12, Appendix C). While there was an apparent clustering of high reported gear losses, the number of units of gear lost appeared to be higher in areas greater than 30 metres in depth. This may suggest that the number of units of gear loss was not necessarily single units of fishing gear at these depths but also losses that involved multiple pieces of gear at once (e.g., combinations of traps, groundlines, anchors, buoys, and balloons).

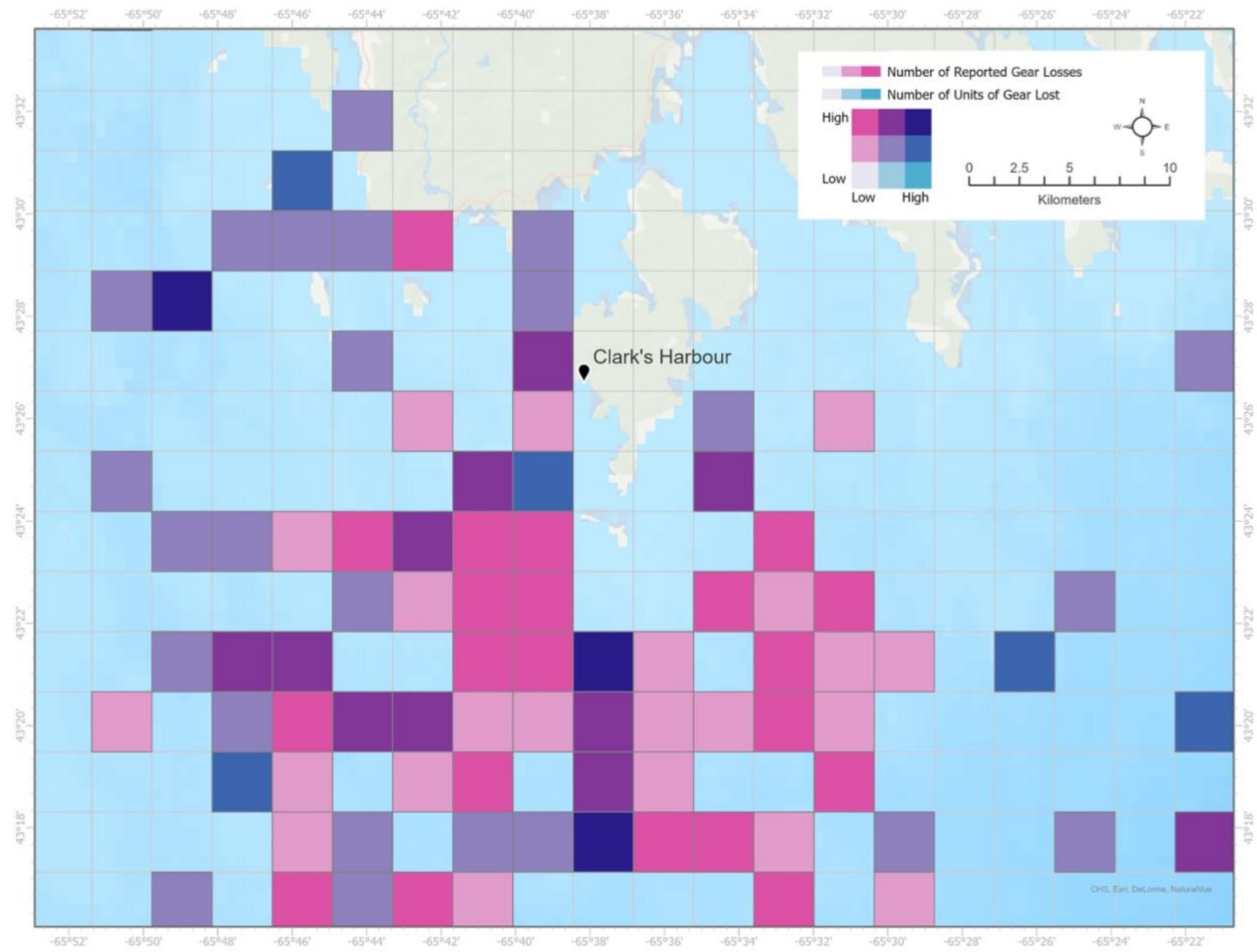


*Figure 12: Aggregation of DFO reported gear losses to 3km x 3km zones. Bivariate colour scheme identifies zones where there are high number of reported gear losses and a high number of units of gear lost.*

## 5.3 Side Scan Sonar Survey

Over the nine days of survey work completed from June 14th to June 22nd, 2021, 90.76 km$^2$ of high-quality side scan sonar tracks were completed within the study area of Clark's Harbour. Twenty-one of the proposed 27 transects were completed from the survey design (Figure 13, Appendix C). Six transects could not be completed due to operational and logistical constraints (i.e., poor weather and challenges of operating in shallow water with negative impacts on data quality). As survey transect lines 12 to 15 represent areas where retrieval effort was conducted in the past (in 2020), the results pertaining to ALDFG identification of this project will focus on the effectiveness of side scan sonar for nearshore, inshore, and offshore transect lines where retrieval activity has not been previously conducted.

The largest survey transect that was completed was Line 7, resulting in a survey length of 17.31km, covering an area of 6.92km$^2$ (Table 7), followed by Line 22 with a survey length of 16.82km and covering an area of 6.73km$^2$. Line 6 was the smallest transect surveyed, comprising a survey length of 2.45km and covering an area of 0.98 km$^2$.

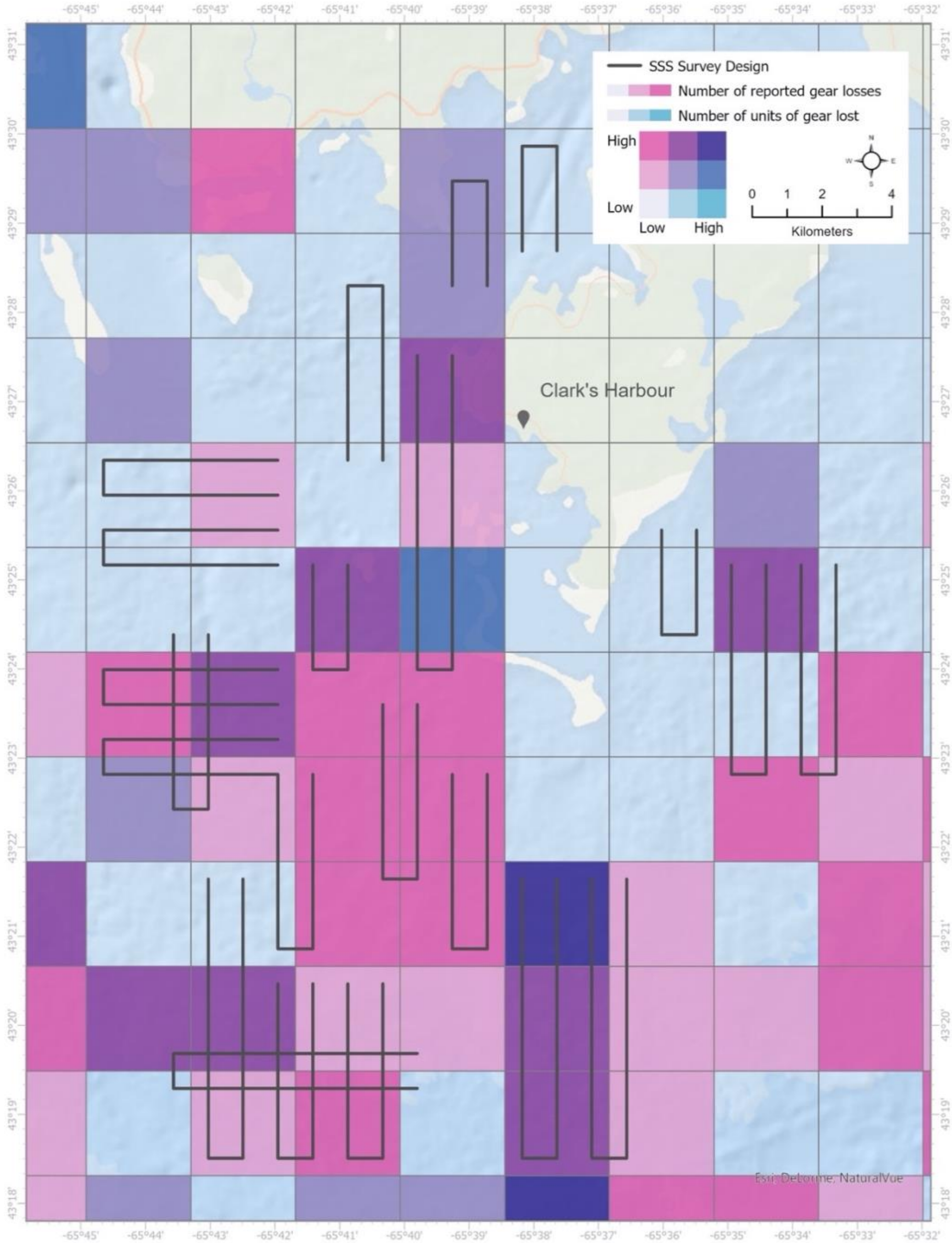


*Figure 13: Side scan sonar (SSS) survey design in Clark's Harbour, Nova Scotia. Survey tracks were positioned to cover grid cells with a range of AFDFG densities, and to map approximately 10 percent of the seafloor within each targeted cell.*

Lines 12 to 15 were omitted from further analysis, as these survey tracks covered an area where ALDFG retrieval efforts had already taken place in 2020. Figure 14 illustrates the post-processed side scan sonar transects within the study area of Clark's Harbour (Appendix C).

*Table 7: Survey transects completed during June 14th to June 22nd, 2021.*

| Survey Transect Number | Completion (%) | Swath Width (km) | Survey Distance (km) | Area Covered ($km^2$) |
|---|---|---|---|---|
| Line 1 | 100 | 0.4 | 14.33 | 5.73 |
| Line 2 | 100 | 0.4 | 16.13 | 6.45 |
| Line 3 | 100 | 0.4 | 10.15 | 4.06 |
| Line 4 | 100+ | 0.4 | 15.27 | 6.10 |
| Line 5 | 100+ | 0.4 | 13.69 | 5.47 |
| Line 6 | 100 | 0.4 | 2.45 | 0.98 |
| Line 7 | 100+ | 0.4 | 17.31 | 6.92 |
| Line 8* | 100+ | 0.4 | 3.10 | 1.24 |
| Line 9** | 100 | 0.4 | N/A | N/A |
| Line 10 | N/A | N/A | N/A | N/A |
| Line 11 | N/A | N/A | N/A | N/A |
| Line 16 | 100+ | 0.4 | 16.53 | 6.61 |
| Line 17 | 100+ | 0.4 | 15.33 | 6.13 |
| Line 18 | N/A | N/A | N/A | N/A |
| Line 19 | 100+ | 0.4 | 15.85 | 6.34 |
| Line 20 | 100+ | 0.4 | 15.58 | 6.23 |
| Line 21 | N/A | N/A | N/A | N/A |
| Line 22 | 100 | 0.4 | 16.82 | 6.73 |
| Line 23 | 100 | 0.4 | 11.26 | 4.5 |
| Line 24 | 100 | 0.4 | 10.50 | 4.2 |
| Line 25 | N/A | N/A | N/A | N/A |
| Line 26 | 100 | 0.4 | 16.06 | 6.42 |
| Line 27 | 100 | 0.4 | 16.62 | 6.65 |
| Total | | | | $90.76km^2$ |

* Line 8 does not represent accurate coverage due to poor data quality.
** Line 9 was not included into the analysis due to poor data quality.

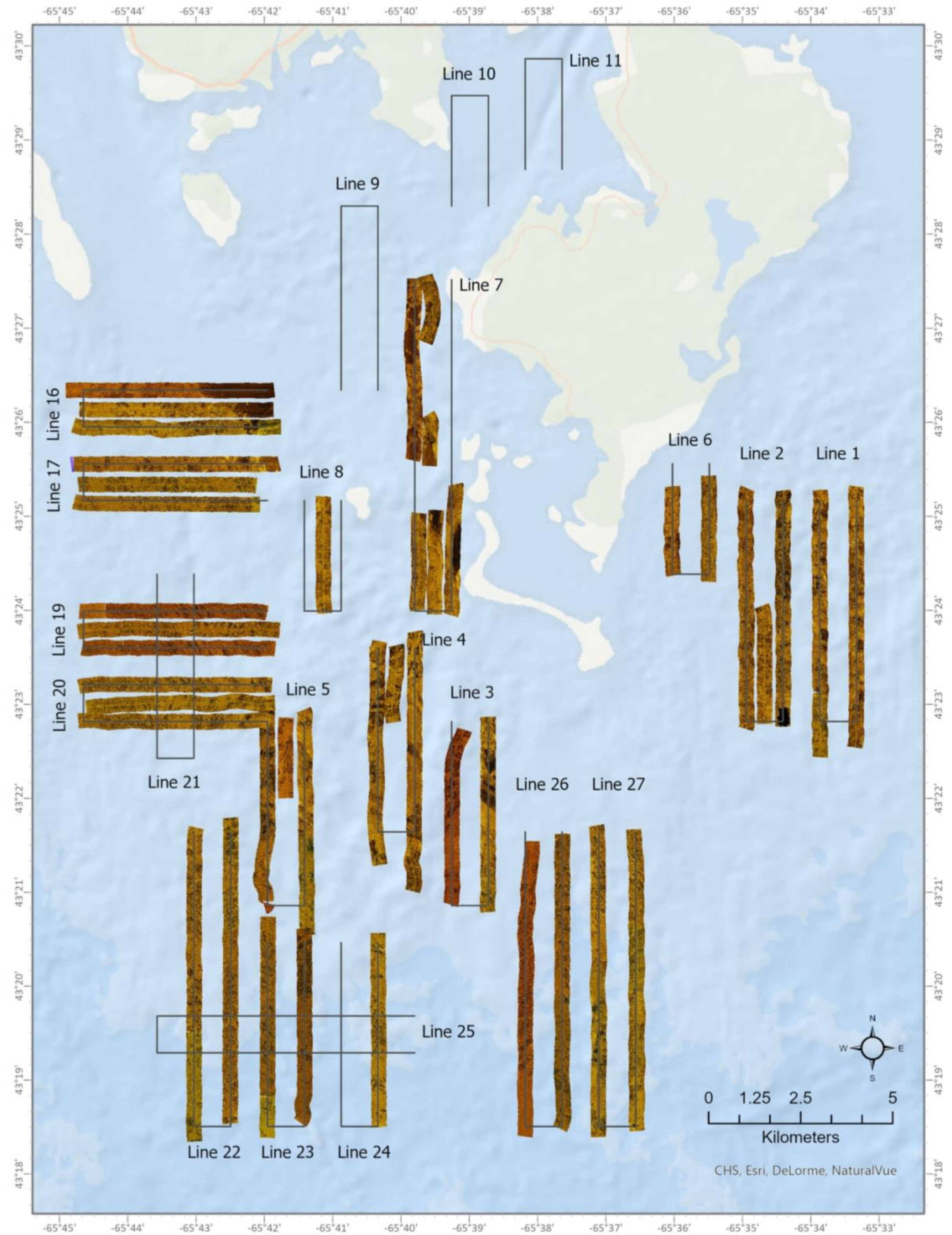


*Figure 14: Post processed side scan sonar survey transects georeferenced within the study area.*

### 5.4 ALDFG Detection

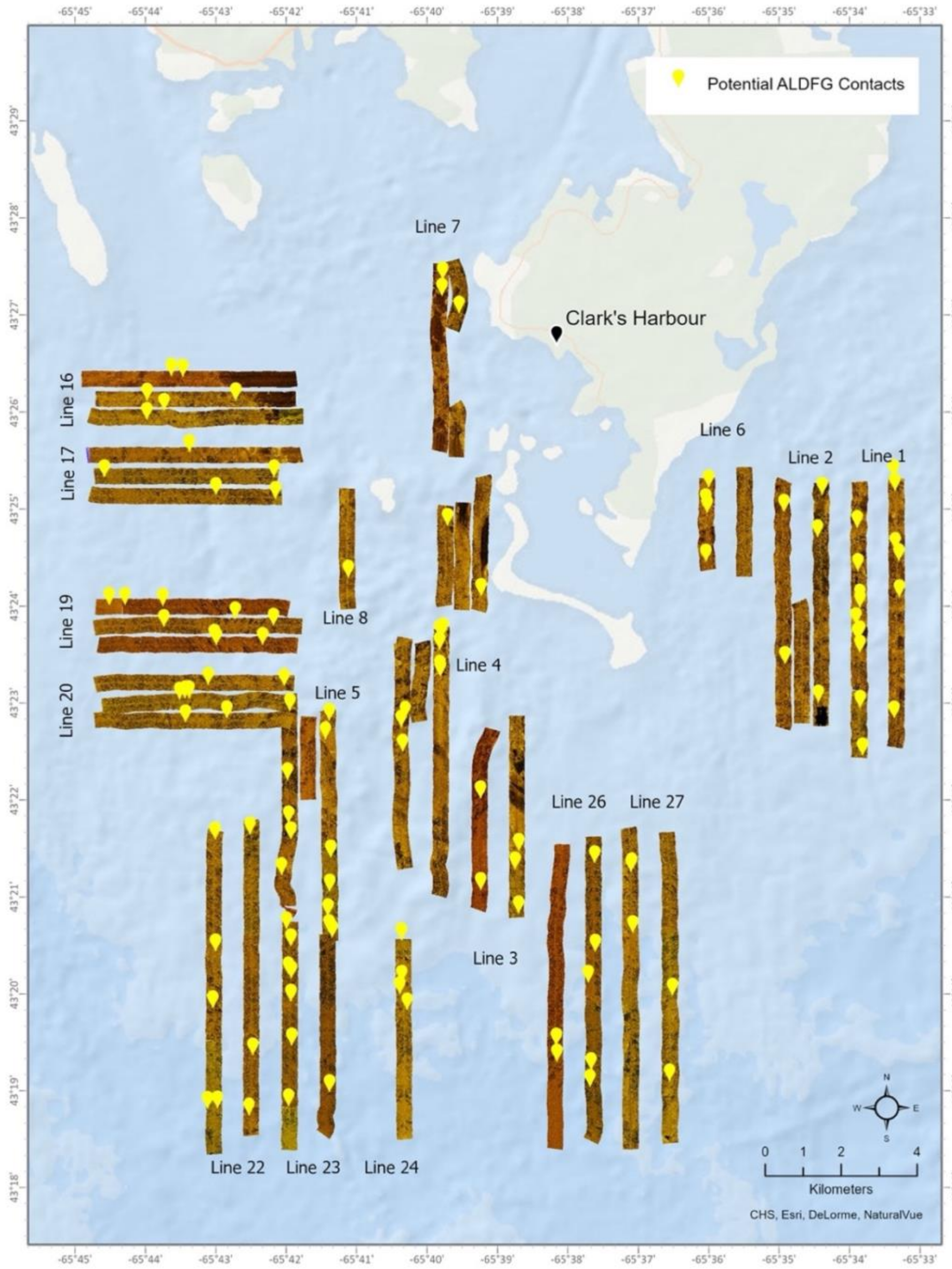
The preliminary identification of ALDFG targets prior to post-processing of the side scan sonar data revealed 161 targets identified. These targets were provisionally identified as lobster traps and other unidentified marine debris. The second comprehensive review of the side scan following post-processing of the data concluded a total of 114 potential targets, revealing that many of these initial targets were unlikely to be ALDFG (Table 8). While transects lines #3 and #20 increased in the number of potential targets identified, 12 transects decreased in potential ALDFG sightings following a second comprehensive review. Line #1 was revealed to be the transect with the highest number of potential ALDFG, while line #5 followed second. Line #23 experienced the most significant decrease following a second comprehensive review of data.

*Table 8: Initial and final number of potential ALDFG identified from the side scan sonar data.*

| Survey Transect Number | Area Covered ($km^2$) | Preliminary review of data: Number of potential ALDFG | Second comprehensive review of data: Number of potential ALDFG |
|---|---|---|---|
| Line 1 | 5.73 | 17 | 16 |
| Line 2 | 6.45 | 8 | 5 |
| Line 3 | 4.06 | 2 | 5 |
| Line 4 | 6.10 | 10 | 8 |
| Line 5 | 5.47 | 20 | 12 |
| Line 6 | 0.98 | 4 | 4 |
| Line 7 | 6.92 | 14 | 5 |
| Line 8* | 1.24 | 7 | 1 |
| Line 16 | 6.61 | 9 | 6 |
| Line 17 | 6.13 | 7 | 5 |
| Line 19 | 6.34 | 9 | 9 |
| Line 20 | 6.23 | 3 | 7 |
| Line 22 | 6.73 | 13 | 8 |
| Line 23 | 4.5 | 20 | 8 |
| Line 24 | 4.2 | 6 | 4 |
| Line 26 | 6.42 | 7 | 7 |
| Line 27 | 6.65 | 5 | 4 |
|  | Total | 161 | 114 |

* Line 8 does not represent accurate coverage due to poor data quality.

A collection of identifiable derelict gear and unidentifiable marine debris were among those selected as potential ALDFG. Of the identifiable fishing gear, lobster traps were most common. Targets on the SSS that did not visually appear to be lobster traps but displayed circular or unconventional shapes were classified as unidentified marine debris. Figure 15 illustrates the distribution of potential ALDFG identified from the SSS data (Appendix C).



CHS, Esri, DeLorme, NaturalVue

*Figure 15: Locations of potential ALDFG amongst survey transects in Clark's Harbour, Nova Scotia.*

In comparing potential contacts to the bivariate hotspot analysis, areas that revealed a high-density of reported gear loss did not yield high-density contacts along survey transects (Figure 16, Appendix C). Lines #1 and #5 yielded the highest potential ALDFG contacts but corresponded with moderately low reported gear loss hotspots. In contrast, SSS transect lines #26 and #27 were surveyed amongst the region's highest density of reported gear losses but revealed a low number of potential derelict gear contacts.

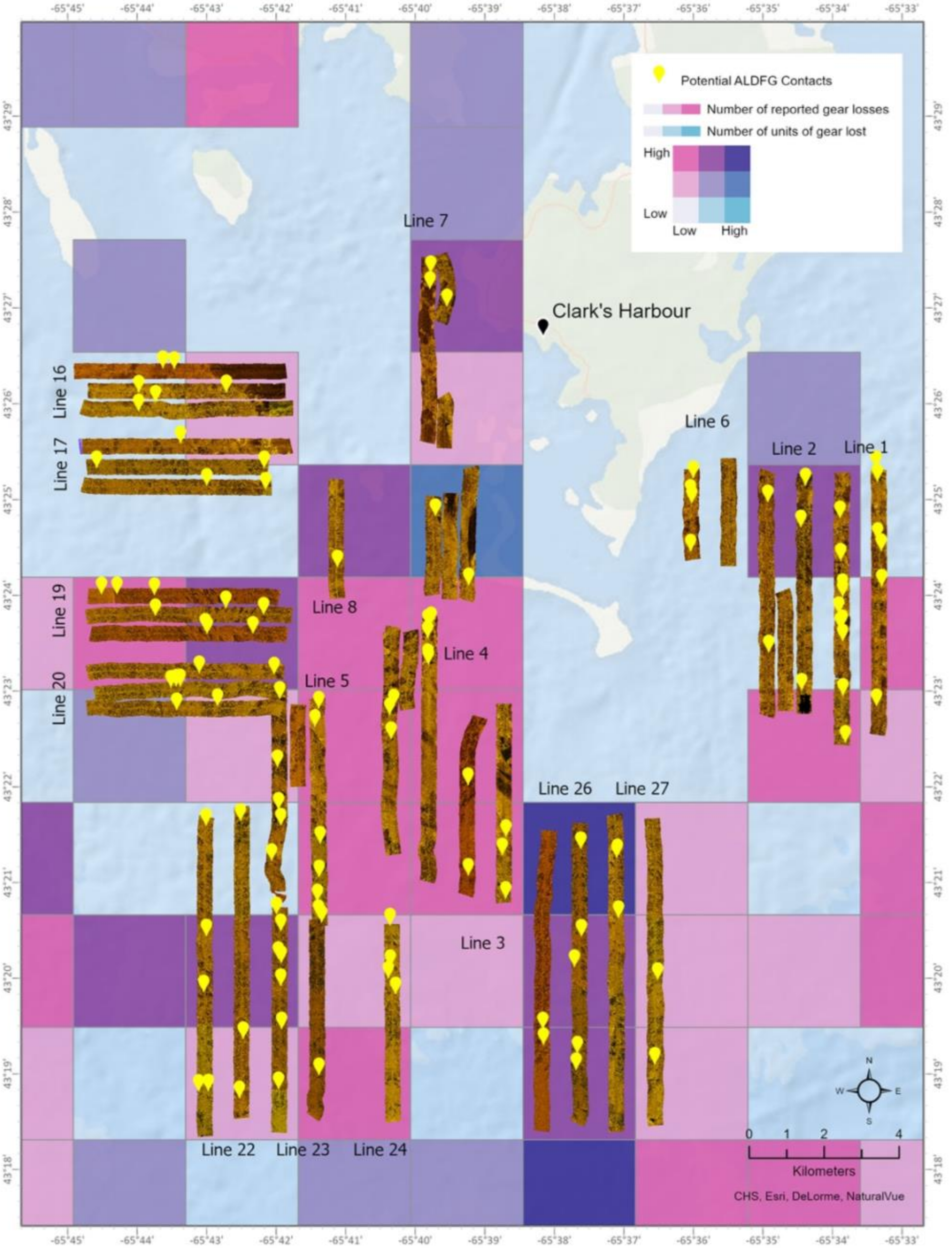


*Figure 16: Locations of potential ALDFG amongst bivariate hotspots of reported gear losses in Clark's Harbour, Nova Scotia.*

## 5.5 Substrate Influences

All side scan sonar data were thoroughly reviewed following the completion of the data collection period. The seafloor habitat visible from the side scan sonar backscatter was classified as either “smooth/homogenous” or “complex habitat”. Smooth/homogenous habitats were defined by areas of low-intensity backscatter, representing unconsolidated low relief substrate (e.g., sand, mud, or mixed sediments). In contrast, complex habitats were characterized by higher intensity backscatter and regions of acoustic shadows, indicative of high relief and complex topography typical of hard bottom, rocky habitats (e.g., outcropping bedrock reefs, moraines and cobble and boulders). The imagery revealed a diversity of seafloor types within these two broad categories, including visible sediment bedforms (sediment ripples and waves) (Figure 17).

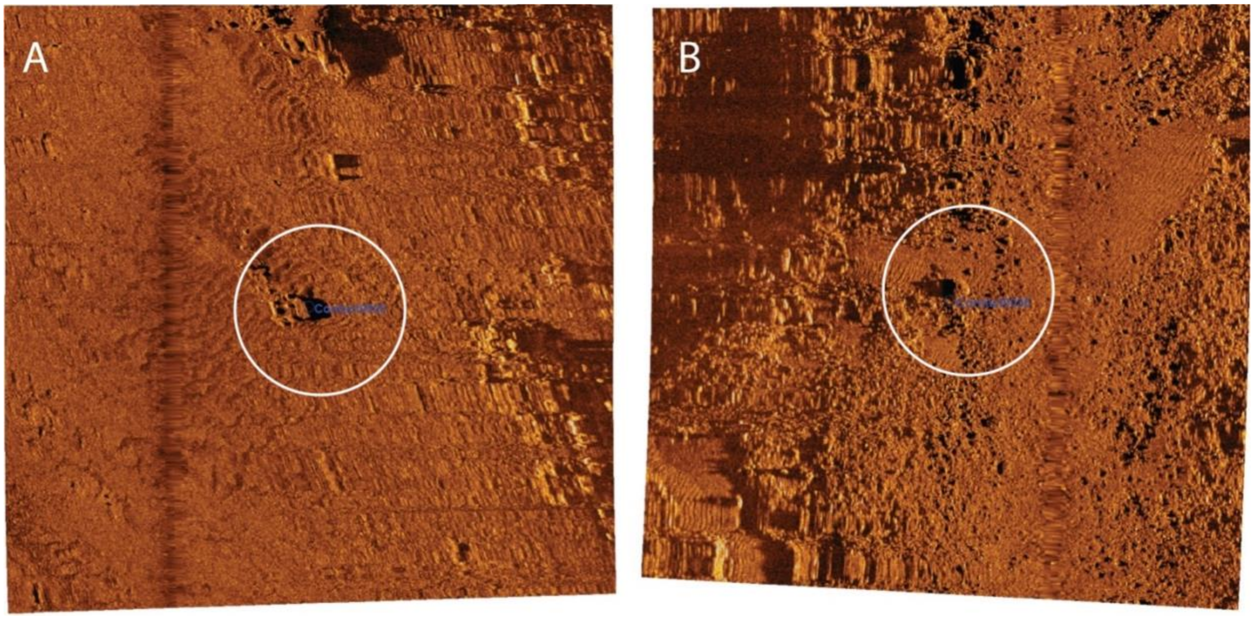


*Figure 17: A) ALDFG target identified in smooth/homogenous substrate (Line #5). B) ALDFG target identified in complex seafloor (Line #1).*

The secondary review of the data reduced the number of potential ALDFG targets, where the reduction was attributed to the challenges of identifying targets on complex bottom types. Figure 18 illustrates the complexities of identifying ALDFG targets over different seafloor substrates (complex vs. smooth/homogenous). In regions of smooth/homogenous substrate, potential ALDFG materials are more easily identifiable than potential ALDFG targets on complex seafloor. In areas of high seafloor structural complexity, ALDFG detection was more difficult due to acoustic shadows, often creating misleading features within the data. Further, side scan sonar data collected over sediments of larger grain sizes (e.g., cobbles and boulders) can "hide" the presence of traps and lead to the conclusion that ALDFG are more prevalent in less complex, homogenous and/or low-relief seafloor types.

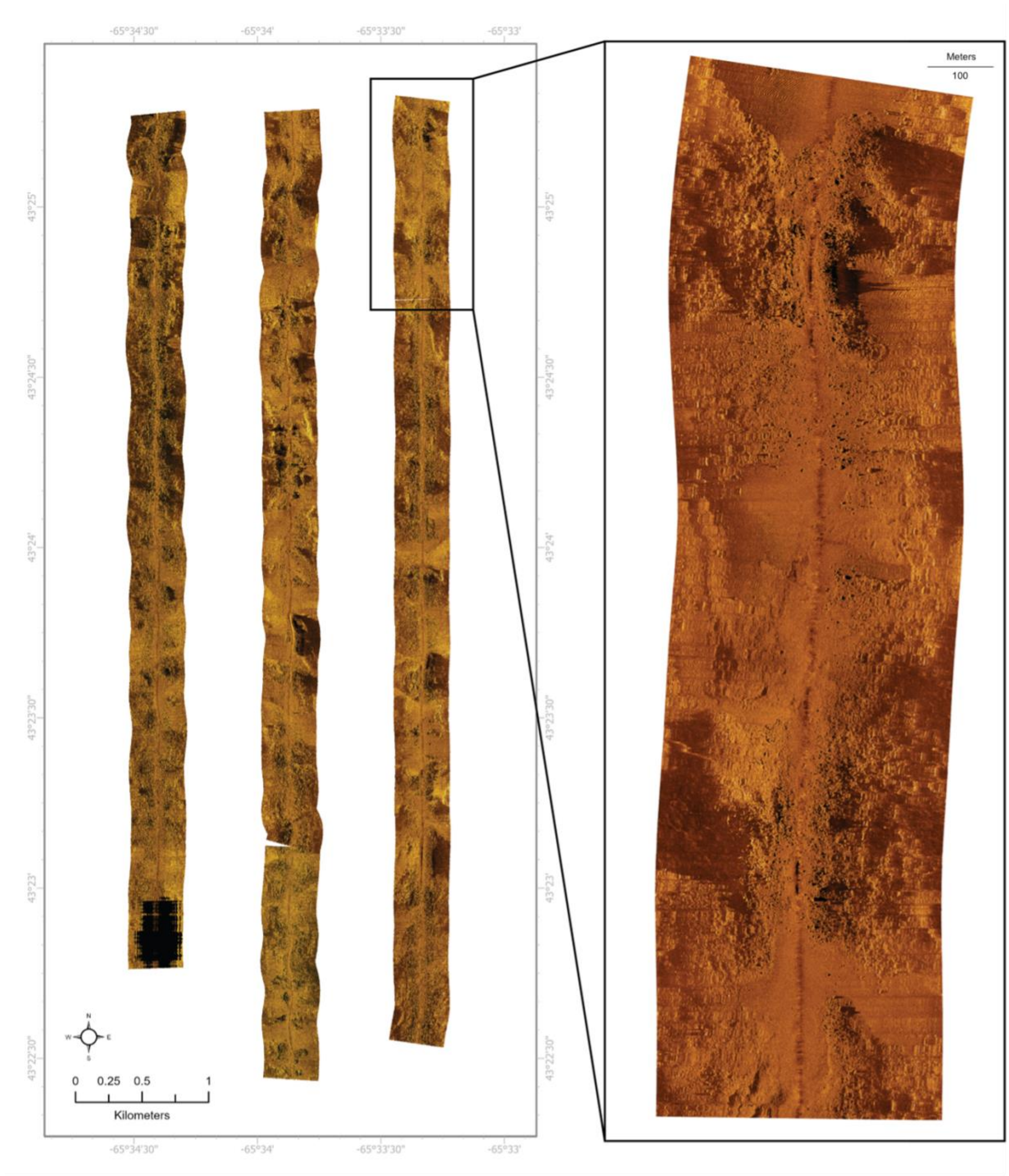


*Figure 18: Section of Line 1 illustrating the backscatter intensities along the survey transect. The survey line comprises of areas of smooth/homogenous habitat, such as fine grain sand or mud, as well as complex habitat, such as rocky bottom types.*

## 5.6 Gear Retrieved

Within the wider Coastal Action lost gear retrieval mission, retrieval efforts were dispersed throughout southwest Nova Scotia in LFA 33, 34, and 35 (Figure 19, Appendix C). Buoys, dragger cable, partial items, rope, traps, and other objects, such as aquaculture netting, were removed from the ocean floor. Amongst the retrieved gear, 66 percent of the total weight of debris comprised lobster traps.

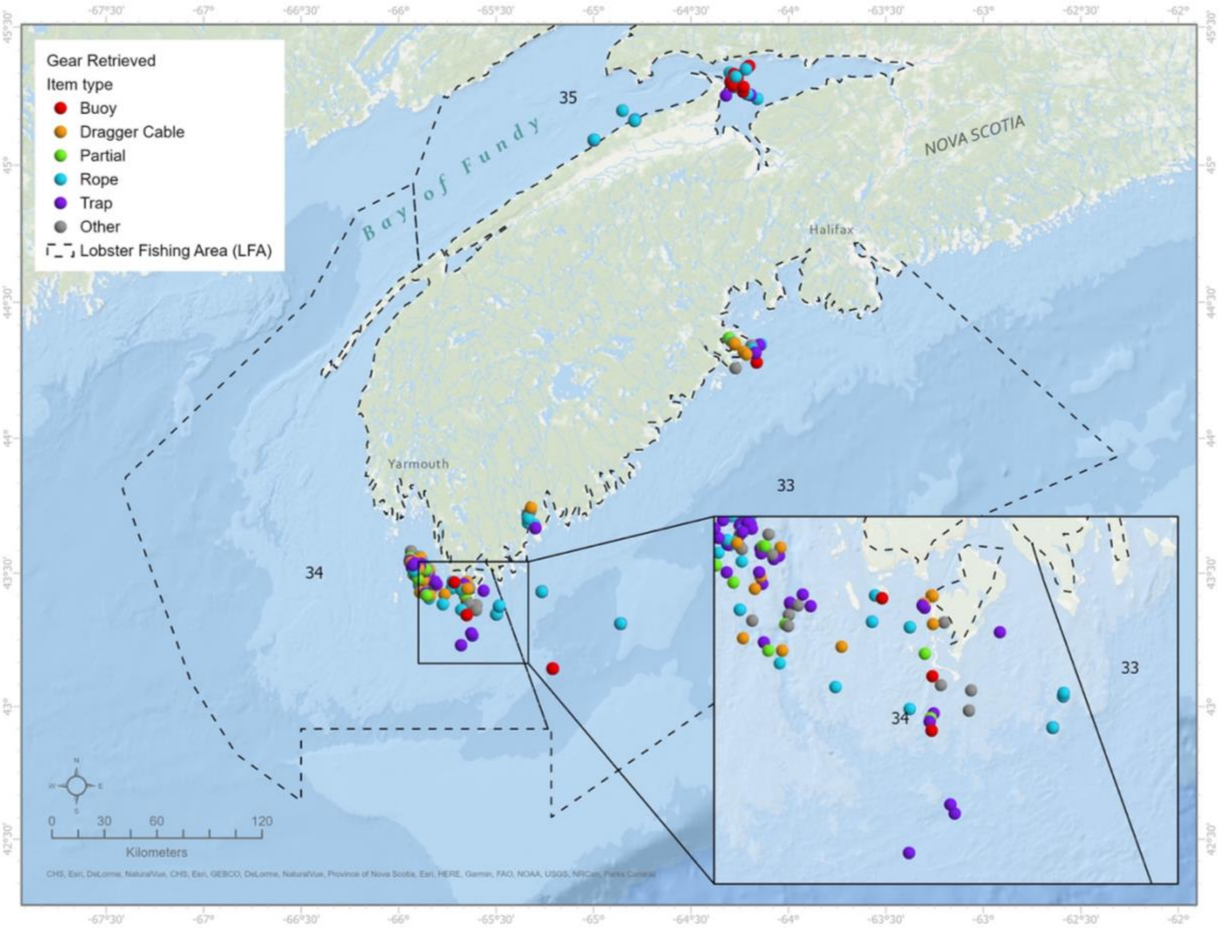


*Figure 19: Gear retrieved from Coastal Action Ghost Gear retrieval mission in LFA 33, 34, 35 during 2021.*

During the 15 days allocated for retrieval in the Clark's Harbour region, 109 tows were completed, where approximately 71.5 percent were considered "NIL" tows, where no gear was retrieved. The average tow length was approximately 2 kilometres before the grapple was pulled up and brought aboard safely. *MV Once Upon a Tide* completed a total tow length of 253 km. Of the total gear retrieved, 46 percent were lobster traps. During the retrieval mission, 14 items of surface gear were retrieved, while 55 items of benthic gear were retrieved in Clark's Harbour

(Table 9). Despite a high density of gear losses in Clark’s Harbour, it was apparent that a greater amount of gear was retrieved compared to other locations, such as Lobster Bay.

*Table 9: Retrieved items from the Clarks Harbour retrieval area.*

| | |
|---|---|
| Number of traps | 33 |
| Number of traps to compound | 18 |
| Number of partial traps | 2 |
| Number of buoys retrieved | 10 |
| Weight of rope retrieved (kg) | 159.45 |
| Length of rope retrieved (ft) | 3236 |
| Weight of cable retrieved (kg) | 553 |
| Weight of “other” items retrieved (kg) | 205.02 |
| Total weight of gear retrieved (kg) | 2111.47 |
| Number of lobsters | 41 |
| Number of fish released | 8 |
| Number of species at risk released | 5 |
| Mean age of traps | 2.4 |
| Median age of traps | 1 |
| Maximum age of traps | 14 |
| Total number of tows | 109 |
| Number of NIL tows | 78 |
| Total number of days completed | 15 |
| Surface gear retrieved | 14 |
| Benthic gear retrieved | 55 |
| Illegal traps retrieved | 0 |
| Irretrievable gear | 2 |
| Surface spotted retrievals | 8 |

Seven items were retrieved between transect lines #7 and #3 alongside scan sonar survey transects. While the predominant items retrieved along survey transects were lobster traps, other items such as dragger cable, partial objects, buoys, and rope were amongst objects that were retrieved near survey transects. Retrieval bottom tows that were completed over side scan transects and then hauled gear outside of the transect may have picked up potential ALDFG targets imaged on the SSS. As the towing stopped outside the transect, tow lines indicate that bottom towing occurred along survey transects in varying directions before hauling the grapple to remove snagged gear (Figure 20, Appendix C). Further, retrieval tow lines indicate that multiple tows were completed within an area before the gear was snagged.

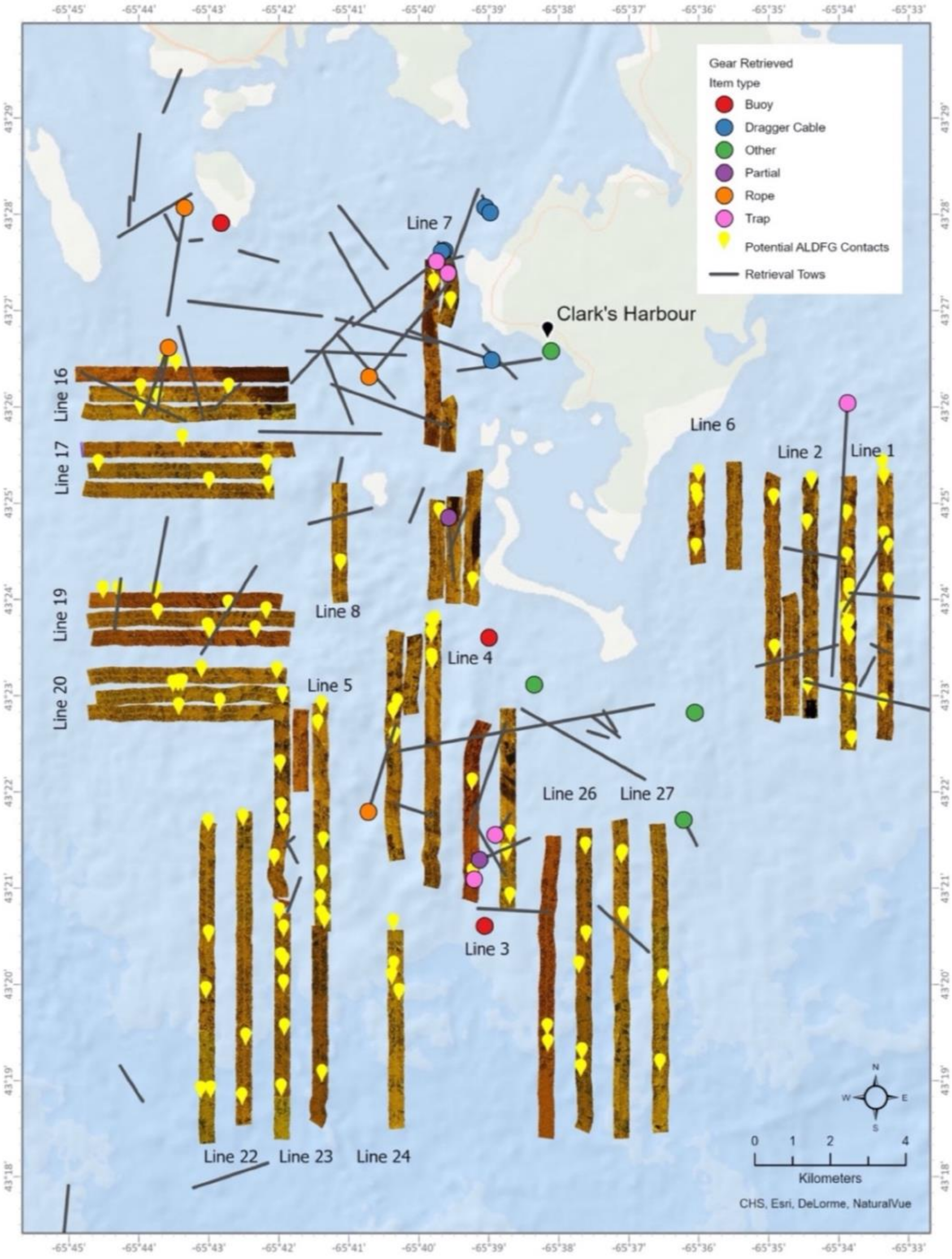


*Figure 20: Retrieved objects, retrieval tow lines displayed in relation to locations of potential ALDFG contacts.*

As displayed in Figure 21, retrieval tows were completed over the side scan transects. Inset A illustrates the retrieval of two lobster traps; however, it does not overlap any potential ALDFG locations. Similarly, insets B and C reveal that partial items and lobster traps have been retrieved from areas covered by the SSS which did not show any potential ALDFG targets. Along transect line #3 in inset C, one item (lobster trap) was confirmed retrieved from ALDFG detected on the SSS. Transect line #16 revealed that the retrieval vessel track passed two locations of potential ALDFG identified on the SSS before managing to retrieve rope (Figure 21 D, Appendix C). As revealed in the geo-referenced images, a combination of smooth/homogenous and complex habitats is portrayed throughout, indicating that potential ALDFG can be caught or snarled in various bottom types.

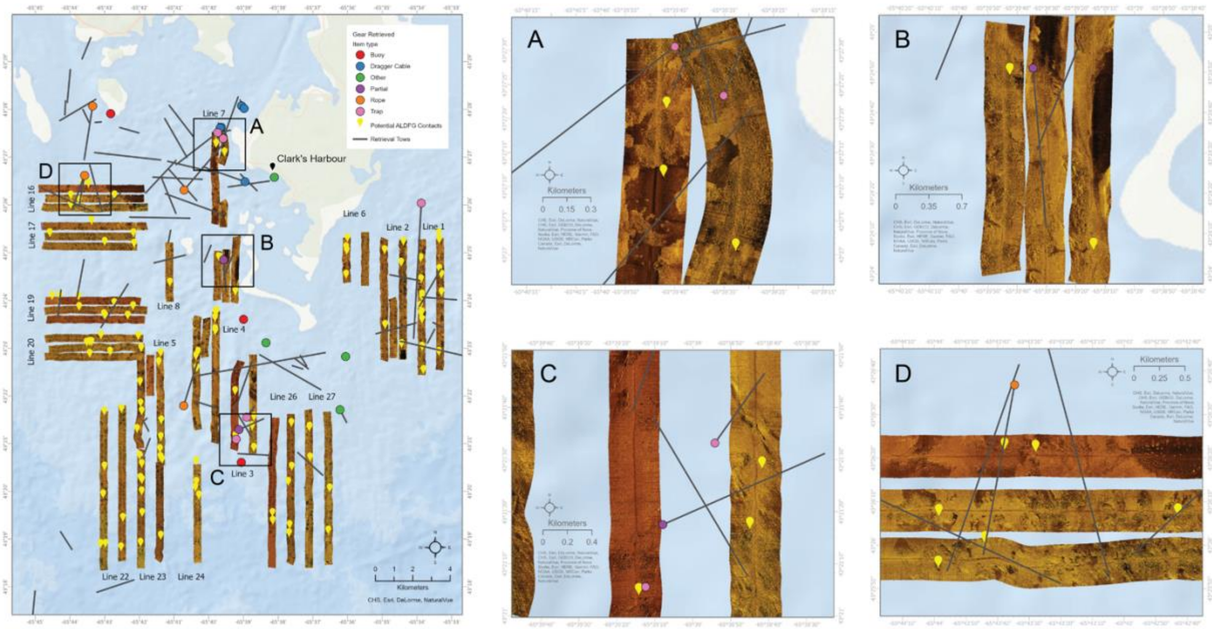


*Figure 21: Retrieval tows overlayed on side scan sonar transects, illustrating locations of gear retrieved in relation to bottom type.*

# 6.0 Discussion

This project aimed at researching the effectiveness of side-scan sonar in detecting lost fishing gear, as well as providing a method in developing gear detection surveys. Given that little has been published regarding the use of SSS in large scale ALDFG detection surveys, the study identified some limitations in the use of side scan sonar in large-scale retrieval missions, particularly over complex seafloor habitats. These findings are similar to the baseline experiment by Chosid et al. (2017), where the authors conclude that smooth/homogenous bottom types yield a higher detection rate of ALDFG compared to areas of complex seafloor. Although international organizations aimed at reducing ghost gear impacts in the marine environment promote the use of side scan sonar (FAO, 2016; Global Ghost Gear Initiative, 2017), this project revealed that there are some limitations in the use of this technology to inform large scale retrieval missions. Recommendations on the use for side scan sonar for ALDFG detection and retrieval should be expanded to include specific recommendations on the acoustic instrument specifications, site selection strategies, survey design considerations, sonar analyst capabilities, translating information of potential targets to retrieval captains, and costs to operate.

## 6.1 Gear Detection Planning and Operation

A review of the literature revealed only one research study (Clark et al., 2012) mapped fishing intensities (traps fished/year) to inform gear detection survey efforts. Currently, the most recent dataset regarding lobster fishing intensities from DFO dates from 2014. To improve the support for continuing detection and retrieval efforts of ALDFG, more up-to-date published data regarding fishing pressures is required from DFO. The authors of the dataset (Coffen-Smout et al., 2013) indicate that the maps should be updated every 3 to 5 years; however, no further data have been published since time of this publication. While fishing pressure datasets obtained from DFO were considered too coarse for the scale of this project, reported lost gear was the best available data regarding the most up-to-date information on fishing whereabouts at the time of this study. As the DFO reported lost gear data from 2019 to 2021 provided was merged into one dataset, it is recommended to conduct yearly hotspot analyses to identify locations where spatial clusters of ALDFG may change temporally.

Although environmental datasets have not been recorded in academic literature to inform locations for gear detection, it is emphasized to capture different elements of the marine environment to fully comprehend the extent of the study area. This project combined environmental datasets, fishing pressures and hotspots to inform site selection of gear detection surveys. Environmental datasets such as seafloor bathymetry, mean annual surface currents and mean annual bottom currents provide information on environmental conditions in areas of higher lobster fishing intensities and reported locations of lost gear. A general understanding of potential movement could be obtained from the information; however, local currents may present more complex results. A detailed model may capture variables, such as bottom roughness, which can be incorporated at a finer resolution.

While geospatial datasets provided knowledge into the site selection of a study area, it also highlighted the complexities with gear detection and retrieval missions. As marine environments present dynamic conditions, gear can easily move with strong currents. Using GPS locations and underwater photography in Florida, results from the study conducted by Lewis et al. (2009) revealed that lost traps move less in deeper water. Despite this, a significant amount of fishing in Southwest Nova Scotia occurs in swallower environments. Mean annual surface and mean annual bottom currents provided insight into potential gear movement; however, the coarse resolution of the modelled physical oceanographic data does not capture the effects of wind and wave action at a local scale. When gear is initially lost, surface currents can move gear before it settles on the seafloor (Richardson et al., 2021). Once settled, bottom currents influence the stability of the gear, possibly moving derelict gear to alternate locations, or burying it within the sediment (Lewis et al., 2009). Oceanographic currents modelled at a finer resolution may be able to provide understanding with regards to source and sink of ALDFG. Without an ocean circulation model at an appropriate resolution, predicting possible locations of gear movement from ocean currents is extremely challenging.

At-sea weather conditions and shallow depths can compromise the quality of the sonar image, which proved to be a significant component to the successful identification of ALDFG on the seafloor. This agrees with conclusions from previous studies, where methods to improve detecting of ALDFG included increased sonar resolution (Leighton & Evans, 2008) and site selection strategies (Clark et al., 2012). As this project used a dual frequency sonar, operated at a low frequency of 230kHz and a high frequency of 850kHz, instruments with higher resolution may improve the likelihood of correctly identifying embedded traps in smooth/homogenous and complex habitats. While this project did not compare towed side scan sonar to AUV side scan sonars, it is possible that AUV-mounted side scan may result in higher quality data due to the avoidance of vessel movement artefacts in the data. Clearer operating recommendations for side scan sonar acquisition for ALDFG detection are therefore suggested.

Given the fact that this project surveyed 10 percent of a 3km x 3km cell, this research highlighted that locations of high-density hotspots of gear loss do not necessarily correlate to high-density bottom contacts identified from the side scan, and that gear may be moving or settling in other locations, or that the spatial accuracy of reported losses is poor. Surveying 10 percent coverage of each cell was selected based on the number of available survey days. Had additional resources been available, this project could have employed a survey strategy covering 100 percent of the seafloor within the area of interest. Adopting such a survey strategy over a broader region would likely void missing targets, but the significantly higher survey effort would come at a higher financial cost. Given the few published articles regarding ALDFG detection, it becomes clear that more rigorous tools for gear identification are needed to fill the gap in this field.

## 6.2 Derelict Gear Identification

Differentiating between ALDFG contacts and the seafloor sediment can make buried targets difficult to identify with side scan sonar. In mixed and complex habitats, lobster pots were similar in size and shape to larger seafloor sediments (boulders and cobbles). Lab studies conducted by Leighton & Evans (2008) have also noted this difficulty with human-made structures and suggest adjusting signal processing techniques as a potential solution. Increasing the number of pings generated and received from the seafloor can yield imagery at a finer resolution. Chosid et al. (2017) indicate that variables such as coverage, data quality, and location targeting are limitations to the use of side scan sonar for large-scale application.

The capability of the sonar analyst is a significant factor contributing to the success in identifying bottom contacts. The results revealed greater challenges in identifying targets in complex bottom types. The presence of coarse substrates (e.g., cobbles and boulders) could cause a misleading interpretation of potential ALDFG. This can cause false-positive identification of targets (e.g., substrates that look like ALDFG) or actual ALDFG to be missed and interpreted as natural seafloor features. As the initial target identification revealed 161 targets, a second review process was conducted to confirm validity. Upon a second revision, the sonar analyst capabilities significantly improved identifying bottom contacts due to greater exposure delineating bottom type and lost gear, such as lobster traps. As bottom contacts were re-examined, it was revealed that targets in smooth/homogenous habitats were more conspicuous than those in complex habitats, which further aided in discerning lobster traps from other bottom structures. While this information is valuable in identifying training specifications for gear detection analysts, it also highlights the extended time required to correctly identify ALDFG on the seafloor from side scan sonar data. These finding emphasize that detecting lost gear is a challenge for large-scale missions despite the value of visual gear identification.

## 6.3 Application to Large-Scale Retrieval Missions

When operating retrieval projects on restricted timeframes, regardless of sonar analyst capabilities, gear identification is an extensive process which may not be suitable for large-scale retrieval projects. Multiple revisions of processed datasets are recommended to confidently identify potential ALDFG targets. In recent years, increased use of artificial intelligence (AI) has been developed to automate data analysis in identifying ALDFG. Such projects like OpenSideScan, developed by CIDCO (CIDCO, n.d.), provide the ability to improve target identification by developing tools to investigate seafloor environments (Morissette & Gautier, 2020). To operate SSS surveys for large-scale retrieval projects, models driven by AI software to automatically identify objects would significantly reduce time post-processing.

As clear communication is considered an inherently important tool for retrieval missions, translating the locations of ALDFG identified from side scan sonar to retrieval captains can incur challenges. As initial contacts were provided in latitude (y) and longitude (x) coordinates in a comma-separated value (CSV) format, lack of direct data translation to retrieval vessel AIS devices created difficulties in uploading locations of lost gear for targeted retrieval. Further, given restricted use of technologies and lack of comprehension for data sharing, retrieval captains were unfamiliar with the downloadable sharing browser. Without exact data format transfers, it is uncertain whether data transfers will be useful in large-scale retrieval missions.

In addition, this miscommunication can lead to occurrences where the bottom is surveyed, and retrieval is not completed, resulting in uncertainties of gear detection effectiveness. The retrieval mission in Clark’s Harbour revealed that only one item of derelict gear was confirmed retrieved along transects of the surveyed bottom. As there were difficulties interpreting gear from complex habitats, it is inconclusive whether gear retrieved is the exact gear observed on the bottom from the high-resolution side scan imagery. Further, given that tows were on average two kilometres in length, it is difficult to confirm whether potential ALDFG contacts that were retrieved just outside the transect were within the SSS imagery or from elsewhere along the towed track. One limitation to the retrieval tow data is that not all tracks from the vessel are linear. The retrieval tow distances were based on coordinates of when the grapple was submerged into the water (start) and pulled out once the gear was snagged (end). This method was used in place of the absence of AIS data. If AIS data had been provided, vessel tracks might have displayed a different towing pattern.

While insight from an anonymous survey conducted by Coastal Action on fishers' local knowledge helped contribute to the site selection of this project, this research study acknowledges that qualitative research was not included as part of gear detection planning. Despite this, ALDFG retrieval efforts included regional fishers, who used local knowledge to guide locations for gear cleanup. As a large portion of ALDFG was retrieved without side scan sonar coverage, this finding indicates that retrieval efforts without surveying can still deliver a high rate of removal success. It must be noted that including local knowledge in the gear detection planning process may yield greater success for large-scale retrieval missions, as was demonstrated by retrieval efforts around Clarkes Harbour in this project.

## 6.4 Cost to Operate

While SSS may provide information on the natural seabed features and ALDFG contacts on the seafloor, gear detection using this approach represents a high cost. To date, no published research has conducted a cost-benefit analysis to assess the potential for adopting side scan sonar technologies for large-scale retrieval missions. Our research has provided information to bridge this knowledge gap. The estimated cost of the entire SSS operation (e.g., survey preparation, vessel charter, field personnel, data acquisition, and post-processing) was between CAD$7,050 – 8,400 a day, totalling between CAD$78,020 – 94,220 (Table 10). Since a student completed survey preparation and data processing at a student rate, commercial costs would be expected to exceed CAD$100,000 for the total mission. Based on the survey costs presented in Table 10, a cost of between CAD$743 to $897 is estimated to survey a 1km$^2$ area at bottom coverage of 100 percent. Based on this metric, surveying the entire study area of Clark's Harbour (561km$^2$) in full coverage would cost approximately between CAD$417,000 to $503,000. The costs calculated above do not take into account expenses sch as accommodations, food, or travel, which are additional factors to consider when applying SSS for retrieval missions. As funded organizations for ALDFG cleanup choose to include SSS surveys for gear detection prior to retrieval missions, the breakdown of expenses may provide insight into the practicality of including gear detection into their agenda.

### 6.5 Alternatives Uses

Although there are limitations regarding SSS for gear detection for large-scale retrieval missions, the application of side scan sonar can have positive outcomes in different scenarios. Given the non-invasive nature of SSS, gear detection may provide significant benefits in areas at a smaller scale where sensitive benthic habitats are present. As bottom towing can alter the composition of benthic ecosystems due to abrasion from grapples, side scan sonar can act as a tool to determine appropriate gear removal methods. Given the uncertainties around gear movement in Southwest Nova Scotia, the use of SSS can also facilitate research to understand how various types of fishing gear moves from oceanographic currents.

*Table 10: Cost-benefit table outlining the total cost (CAD) for detection gear losses using side scan sonar (SSS).*

| Proposed Action | Benefit | Cost | Cost per day | Cost for SSS Surveying |
|---|---|---|---|---|
| Survey Preparation | | | | |
| Compilation of Geospatial Records | Highlighting hotspot areas. | $20/ hour * | $160 | $1,100 |
| Survey Design | Informing precise plan for survey mission. | $20/ hour * | $160 | |
| | | Total | $320 | $1,100 |
| Data Acquisition | | | | |
| Towfish | Data collection tool. | $3,000/per day | $3,000 | $36,000 |
| Vessel Charter | Required for functioning of towfish for data collection. | $225/hour | $2,250 - $2,700 | $27,000 – $32,400 |
| Hours spent collecting data | Required for completion of survey transect lines. | 10-12 hours per day | | |
| Staff | Required for data collection in real-time. | $300/per person per day | $900 - $1,800 | $10,800 – $21,600 |
| Number of staff onboard (inclusive of Captain) | Required for data collection in real-time. | 3-6 per day | | |
| | | Total | $6,150 -7,500 | $73,800 – 90,000 |
| Post-processing | | | | |
| SonarWiz 7 | Post-processing software | $100/day | $100 | $1,200 |
| | Training Workshop | $320 | $320 | $320 |
| Number of Sonar Analysts | Required for post-processing. | 1 person at $20/ hour * | $160 | $1,600 |
| Hours spent processing and analyzing data | Tasks include applying corrections, identification of ALDFG contacts, map production, and analysis. | 80 hours | | |
| | | Total | $580 | $3,120 |
| | | Subtotal | $7,050 – 8,400 | $78,020 – 94,220 |

* Student position hourly rate.

# 7.0 Recommendations and Conclusions

Identifying ALDFG on the seafloor is no simple task and removing of marine debris from benthic habitats is difficult. Based on the analysis from this research, the planning, acquisition, and processing of side scan sonar data required for gear detection and retrieval missions is not feasible for large-scale retrieval missions. While gear can be located using side scan sonar, greater grappling precision, and full coverage SSS surveys is recommended at smaller geographic scales. Retrieval missions that grapple using the bottom towing method may cause extensive damage to sensitive benthic areas. Based on this project's findings, the following recommendations are illustrated to improve gear detection for ALDFG retrieval missions:

1. Knowledge of prime fishing locations and prioritizing identified hotspots through geospatial analyses of reported gear losses may be the most direct way at targeting retrieval areas. A combination of qualitative and quantitative analysis will ultimately strengthen and increase retrieval activities' precision while potentially improving the likelihood of success.
2. In locations where complex bottom types are present, difficulties in identifying lost gear may continue to exist despite an increase in sonar analyst capabilities and higher resolution imagery. While results of the final gear detection interpretation did refine results in comparison to the initial gear detection exercise, locations of retrieved gear revealed insight into the effectiveness of its use in large-scale missions.
3. A significant amount of gear was retrieved from the guidance of local knowledge holders where side scan sonar coverage was not present. Retrieval fishers hold a wealth of knowledge that can be pivotal if incorporated in the gear detection process, which may ultimately contribute to higher gear detection and retrieval success rates. An example of including fishers in gear detection planning could include a mapping exercise to inform seafloor mapping design strategies.
4. Retrieval processes that involve blindly bottom towing the ocean floor can have negative consequences to benthic ecosystems. The use of side scan sonar is a non-invasive method to evaluate the quantity of potential ALDFG contacts on

the seafloor. As such, acoustic detection is encouraged to evaluate known bottom habitats that are more sensitive to the impacts caused by bottom towing.

5. Gear movement studies in southwest Nova Scotia are recommended to understand the influence of bottom type and environmental parameters. Understanding the impacts of seasonal storms on buoyed and unbuoyed traps may yield approximate distances to assess benthic ecosystem damage further.
6. Advancements in oceanographic modelling at local scales, environmental parameters such as habitat maps, and frequent updating of available fishing pressure data are required to evaluate the source and sink of ALDFG further. To best target gear retrieval, spatial data from government agencies should be made publicly available to inform retrieval areas used with local knowledge.
7. Complete coverage of an area as large as southwest Nova Scotia would be extremely costly and may not be suitable to conduct annually. As such, it is recommended to operate SSS in large-scale retrieval missions where targeted retrieval may be necessary due to sensitive bottom habitats. Given the gap in outlining operation costs for SSS surveys, it is recommended to increase the level of transparency amongst larger organizations when promoting the use of SSS in large-scale retrieval missions.

Overall, this study evaluated the feasibility of applying side scan sonar for gear detection in large-scale retrieval missions and emphasizes that there are apparent limitations in research regarding the use of gear detection. As gear detection presents a significant cost, organizations are urged to evaluate the benefits of the application and coordinate missions based on a combination of fishing pressures, reported gear losses, environmental parameters, and fisher’s knowledge in future applications.

# References

Al-Masroori, H., Al-Oufi, H., & McShane, P. (2009). Causes and mitigations on trap ghost fishing in Oman: scientific approach to local fishers' perception. *J. Fish. Aquatic Sci., 4*, 129–135.

Ambrose, K. K., Box, C., Boxall, J., Brooks, A., Eriksen, M., Fabres, J., . . . Walker, T. R. (2019). Spatial trends and drivers of marine debris accumulation on shorelines in South Eleuthera, The Bahamas using citizen science. *Marine Pollution Bulletin, 142*, 145-154.

Angelini, Z., Kinner, N., Thibault, J., Ramsey, P., & Fuld, K. (2019). Marine debris visual identification assessment. *Marine Pollution Bulletin, 142*, 69-75.

Angiolillo, M., & Fortibuoni, T. (2020). Impacts of Marine Litter on Mediterranean Reef Systems: From Shallow to Deep Waters. *Frontiers in Marine Science, 7*.

Arthur, C., Sutton-Grier, A. E., Murphy, P., & Bamford, H. (2014). Out of sight but not out of mind: Harmful effects of derelict traps in selected U.S. coastal waters. *Marine Pollution Bulletin, 86*(1-2), 19-28.

Bernier, R. Y., Jamieson, R. E., & Moore, A. M. (2018). *State of the Atlantic Ocean Synthesis Report.* Fisheries and Oceans Canada. Moncton: Fisheries and Oceans Canada.

Bilkovic, D. M., Havens, K., Stanhope, D., & Angstadt, K. (2014). Derelict fishing gear in Chesapeake Bay, Virginia: Spatial patterns and implications for marine fauna. *Marine Pollution Bulletin, 80*, 114-123.

Black Laser Learning. (2018). *HULL MOUNTED VS TOWED SIDE SCAN SONAR SYSTEMS: A SONAR EXPERT'S PERSPECTIVE*. Retrieved April 2021, from https://blacklaserlearning.com/hull-mounted-vs-towed-side-scan-sonar-systems-a-sonar-experts-perspective/

Borrelli, M., Ludwig, L., Legare, B., Smith, T., & Nichols, O. (2018). Don't Have a Pot to Ping in: The Efficacy of Using Sidescan Sonar to Detect, Locate and Identify Derelict Fishing Gear. SAN DIEGO: Sixth International Marine Debris Conference.

Brown, A. H., & Niedzwecki, J. M. (2020). Assessing the risk of whale entanglement with fishing gear debris. *Marine Pollution Bulletin, 161,* 1-14.

Brown, C. J., Smith, S. J., Lawton, P., & Anderson, J. T. (2011). Benthic habitat mapping: A review of progress towards improved understanding of the spatial ecology of the seafloor using acoustic techniques. *Estuarine, Coastal and Shelf Science, 92*, 502-520.

Bôas, A. B., Ardhuin, F., Ayet, A., Bourassa, M. A., Brandt, P., Chapron, B., . . . Li, Q. (2019). Integrated Observations of Global Surface Winds, Currents, and Waves: Requirements and Challenges for the Next Decade. *Frontiers in Marine Science, 6*, 1-34.

Chen, B., Yang, Y., Zhou, J., Zhuang, Y., & McFarland, M. (2021). Damage detection of underwater foundation of a Chinese ancient stone arch bridge via sonar-based techniques. *Measurement, 169*.

Cho, D.-O. (2011). Removing derelict fishing gear from the deep seabed of the East Sea. *Marine Policy, 35*, 610-614.

Chosid, D. F. (2017). *Development of Side Scan Sonar Methodology to Survey Derelict Lobster Pots in Simple and Complex Habitats in Massachusetts.* Government of Massachusetts.

CIDCO. (n.d.). *Open Sidescan*. Retrieved from https://opensidescan.cidco.ca/

Clark, R., Pittman, S. J., Battista, T. A., & Caldow, C. (2012). *Survey and Impact Assessment of Derelict Fish Traps in St. Thomas and St. John, U.S. Virgin Islands.* NOAA National Centers for Coastal Ocean Science. Silver Spring: National Oceanic Atmospheric Administration.

Coastal Action. (2021). Retrieved abandoned, lost, or otherwise discarded fishing gear.

Coffen-Smout, S., Shervill, D., Sam, D., Denton, C., & Tremblay, J. (2013). *Mapping Inshore Lobster Landings and Fishing Effort on a Maritimes Region Modified Grid System.* Dartmouth: Fisheries and Oceans Canada.

Dawe, N., Kendall, R. A., Goodick, M., & Smith, S. (2020). *End-of-Life Fishing Gear Management in Nova Scotia.* Fishing Gear Coalition of Atlantic Canada.

Demestre, M., Muntadas, A., Juan, S. d., Mitilineou, C., Sartor, P., Mas, J., . . . Martín, J. (2015). The need for fine-scale assessment of trawl fishing effort to inform on an ecosystem approach to fisheries: Exploring three data sources in Mediterranean trawling grounds. *Marine Policy, 62*, 134-143.

DFO. (2019). *Lobster Fishing Areas 27 - 38 Integrated Fisheries Management Plan*. Retrieved 10 24, 2021, from https://www.dfo-mpo.gc.ca/fisheries-peches/ifmp-gmp/maritimes/2019/inshore-lobster-eng.html

DFO. (2019). *Seafisheries landed value by province, 2019*. Retrieved from Fisheries and Oceans Canada: https://www.dfo-mpo.gc.ca/stats/commercial/land-debarq/sea-maritimes/s2019pv-eng.htm

DFO. (2020). *Combatting marine litter: Ghost gear*. Retrieved April 2021, from https://www.dfo-mpo.gc.ca/fisheries-peches/management-gestion/ghostgear-equipementfantome/index-eng.html

DFO. (2020). *Information for the fishing industry and stakeholders*. Retrieved October 26, 2021, from https://www.dfo-mpo.gc.ca/fisheries-peches/management-gestion/ghostgear-equipementfantome/collaboration-eng.html

DFO. (2020). Lobster Fishing Areas (33,34,35).

DFO. (2020). Small Craft Harbours.

DFO. (2021). Reported Lost Fishing Gear.

Esri. (n.d.). *What is empirical Bayesian kriging?* Retrieved November 2021, from ArcGIS Pro: https://pro.arcgis.com/en/pro-app/latest/help/analysis/geostatistical-analyst/what-is-empirical-bayesian-kriging-.htm

FAO. (2016). *Abandoned, lost and discarded gillnets and trammel nets.* Food and Agriculture Organization of the United Nations. Rome: Food and Agriculture Organization of the United Nations.

FAO. (2020). *The State of World Fisheries and Aquaculture: Sustainability in Action.* Rome: FAO.

Farias, E. G., Preichardt, P. R., & Dantas, D. V. (2018). Influence of fishing activity over the marine debris composition close to coastal jetty. *Environmental Science and Pollution Research, 25*, 16246–16253.

Ferentinos, G., Fakiris, E., Christodoulou, D., Geraga, M., Dimas, X., Georgiou, N., . . . Sotiropoulos, M. (2020). Optimal sidescan sonar and subbottom profiler surveying of ancient wrecks: The ‘Fiskardo’ wreck, Kefallinia Island, Ionian Sea. *Journal of Archaeological Science, 113*.

Fundy North Fisherman's Association. (2016). *Lost-at-sea: Ghost Gear Retrieval Guide.* Fundy North Fisherman Association.

GEBCO. (2021). *Gridded Bathymetry Data*. Retrieved from GEBCO: https://www.gebco.net/data_and_products/gridded_bathymetry_data/

Gilman, E. (2015). Status of international monitoring and management of abandoned, lost and discarded fishing gear and ghost fishing. *Marine Policy, 60*, 225-239.

Global Ghost Gear Initiative. (2017). *Methods to Locate Derelict Fishing Gear in Marine Waters.* Global Ghost Gear Initiative.

Global Ghost Gear Initiative. (2021). *Best Practice Framework for the Management of Fishing Gear.* Global Ghost Gear Initiative.

Goodman, A. J., Brillant, S., Walker, T. R., Bailey, M., & Callaghan, C. (2019). A Ghostly Issue: Managing abandoned, lost and discarded lobster fishing gear in the Bay of Fundy in Eastern Canada. *Ocean and Coastal Management, 181*.

Goodman, A. J., McIntyre, J., Smith, A., Fulton, L., Walker, T. R., & Brown, C. J. (2021). Retrieval of abandoned, lost, and discarded fishing gear in Southwest Nova Scotia, Canada: Preliminary environmental and economic impacts to the commercial lobster industry. *Marine Pollution Bulletin, 171*.

Goodman, A. J., Walker, T. R., Brown, C. J., Wilson, B. R., Gazzola, V., & Sameoto, J. A. (2020). Benthic marine debris in the Bay of Fundy, eastern Canada: Spatial distribution and categorization using seafloor video footage. *Marine Pollution Bulletin, 150*.

Greenan, B. J., Shackell, N. L., Ferguson, K., Greyson, P., Cogswell, A., Brickman, D., . . . Saba, V. S. (2019). Climate Change Vulnerability of American Lobster Fishing Communities in Atlantic Canada. *Frontiers in Marine Science,* 1-18.

Gregory, M. R. (2009). Environmental implications of plastic debris in marine settings—entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. *Philosophical Transactions of the Royal Society, 364*, 2013-2025.

Guillory, V., McMillen-Jackson, A., Hartman, L., Perry, H., Floyd, T., Wagner, T., & Graham, G. (2001). *Blue Crab Derelict Traps and Trap Removal Programs.* Ocean Springs: Gulf States Marine Fisheries Commission.

Hamouda, A. Z., Nassar, M. A., & El-Gharabawy, S. M. (2021). Distinguish seabed objects utilizing different marine acoustic techniques. *Egyptian Journal of Petroleum, 30*, 45-51.

Kane, I. A., & Clare, M. A. (2019). Dispersion, Accumulation, and the Ultimate Fate of Microplastics in Deep-Marine Environments: A Review and Future Directions. *Frontiers in Earth Science, 7*(80), 1-27.

Large, P. A., Graham, N. G., Hareide, N.-R., Misund, R., Rihan, D. J., Mulligan, M. C., . . . Harlay, X. (2009). Lost and abandoned nets in deep-water gillnet fisheries in the

Northeast Atlantic: retrieval exercises and outcomes. *Journal of Marine Science, 66,* 323-333.

Leighton, T., & Evans, R. (2008). The detection by sonar of difficult targets (including centimetre-scale plastic objects and optical fibres) buried in saturated sediment. *Applied Acoustics, 69*, 438-463.

Lewis, C. F., Slade, S. L., Maxwell, K. E., & Matthews, T. R. (2009). Lobster trap impact on coral reefs: Effects of wind-driven trap movement. *New Zealand Journal of Marine and Freshwater Research, 43*(1), 271-282.

Long, W. C., Cummiskey, P. A., & Munk, a. J. (2014). Effects of ghost fishing on the population of red king crab (Paralithodes camtschaticus) in Womens Bay, Kodiak Island, Alaska. *Fishery Bulletin, 112*, 101-111.

Lumpkin, R., & Johnson, G. C. (2013). Global ocean surface velocities from drifters: Mean, variance, El Nin~o–Southern Oscillation response, and seasonal cycle. *Journal of Geophysical Research: Oceans, 118*, 2992–3006.

Macfadyen, G., Huntington, T., & Cappell, R. (2009). *Abandoned, lost or otherwise discarded fishing gear.* Rome: Food and Agriculture Organization of the United Nations.

Macmullen, P., Hareide, N., Furevik, D. M., Larsson, P., Tschernij, V., Dunlin, G., & al., e. (2004, January 1). *A Study to Identify, Quantify and Ameliorate the Impacts of Static Gear Lost at Sea.* Retrieved September 30, 2021, from https://www.seafish.org/document/?id=55615b7b-bfee-40f5-8f64-29529b12bfb6

Masompour, Y., Gorgin, S., Pighambari, S., Karimzadeh, G., Babanejad, M., & Eighani, M. (2018). The impact of ghost fishing on catch rate and composition in the southern T Caspian Sea. *Marine Pollution Bulletin, 135,* 534-539.

Morishige, C., & McElwee, K. (2012). At-sea detection of derelict fishing gear in the North Pacific: An overview. *Marine Pollution Bulletin, 65,* 1-6.

Morissette, G. L., & Gautier, S. (2020). Unsupervised extraction of underwater regions of interest in sidescan sonar imagery. *Journal of Ocean Technology, 15*(1), 95-108.

NOAA. (2015). *NOAA Marine Debris Program FY 2015 Accomplishments Report.* NOAA.

NOAA. (2021). *What is bathymetry?* Retrieved October 27, 2021, from https://oceanservice.noaa.gov/facts/bathymetry.html

Plets, R., Dix, J., & Bates, R. (2013). *Marine geophysics data acquisition, processing and interpretation.* English Heritage.

Rajput, S., & Thakur, N. K. (2016). Chapter 3 - Sedimentation Pattern. In *Geological Controls for Gas Hydrates and Unconventionals* (pp. 69-106). Elsevier.

Richardson, K., Asmutis-Silvia, R., Drinkwin, J., Gilardi, K. V., Giskes, I., Jones, G., . . . Mattila. (2019). Building evidence around ghost gear: Global trends and analysis for sustainable solutions at scale. *Marine Pollution Bulletin, 138*, 222-229.

Richardson, K., Hardesty, B. D., Vince, J. Z., & Wilcox, C. (2021). Global Causes, Drivers, and Prevention Measures for Lost Fishing Gear. *Frontiers in Marine Science, 8*(690447), 1-11.

Ruffell, A., Pringle, J., Cassella, J., Morgan, R., Ferguson, M., Heaton, V., . . . McKinley, J. (2017). The use of geoscience methods for aquatic forensic searches. *Earth-Science Reviews, 171*, 323-337.

Saez, L., Lawson, D., & DeAngelis, M. (2021). *Large whale entanglements off the U.S. West Coast, from 1982–2017.* National Oceanic and Atmospheric Administration. National Oceanic and Atmospheric Administration.

Scheld, A. M., Bilkovic, D. M., & Havens, K. J. (2021). Evaluating optimal removal of derelict blue crab pots in Virginia, US. *Ocean and Coastal Management, 211*, 1-8.

Schultz, J. J., Healy, C. A., Parker, K., & Lowers, B. (2013). Detecting submerged objects: The application of side scan sonar to forensic contexts. *Forensic Science International, 231*, 306-316.

Serdynska, A., & Coffen-Smout, S. (2017). *Mapping Inshore Lobster Landings and Fishing Effort on a Maritimes Region Statistical Grid (2012–2014).* Dartmouth: Fisheries and Oceans Canada.

Shanmugam, G. (2008). Chapter 5 Deep-water Bottom Currents and their Deposits. *Developments in sedimentology , 60*, 59-81.

Stelfox, M., Hudgins, J., & Sweet, M. (2016). A review of ghost gear entanglement amongst marine mammals, reptiles and elasmobranchs. *Marine Pollution Bulletin, 111*, 6-17.

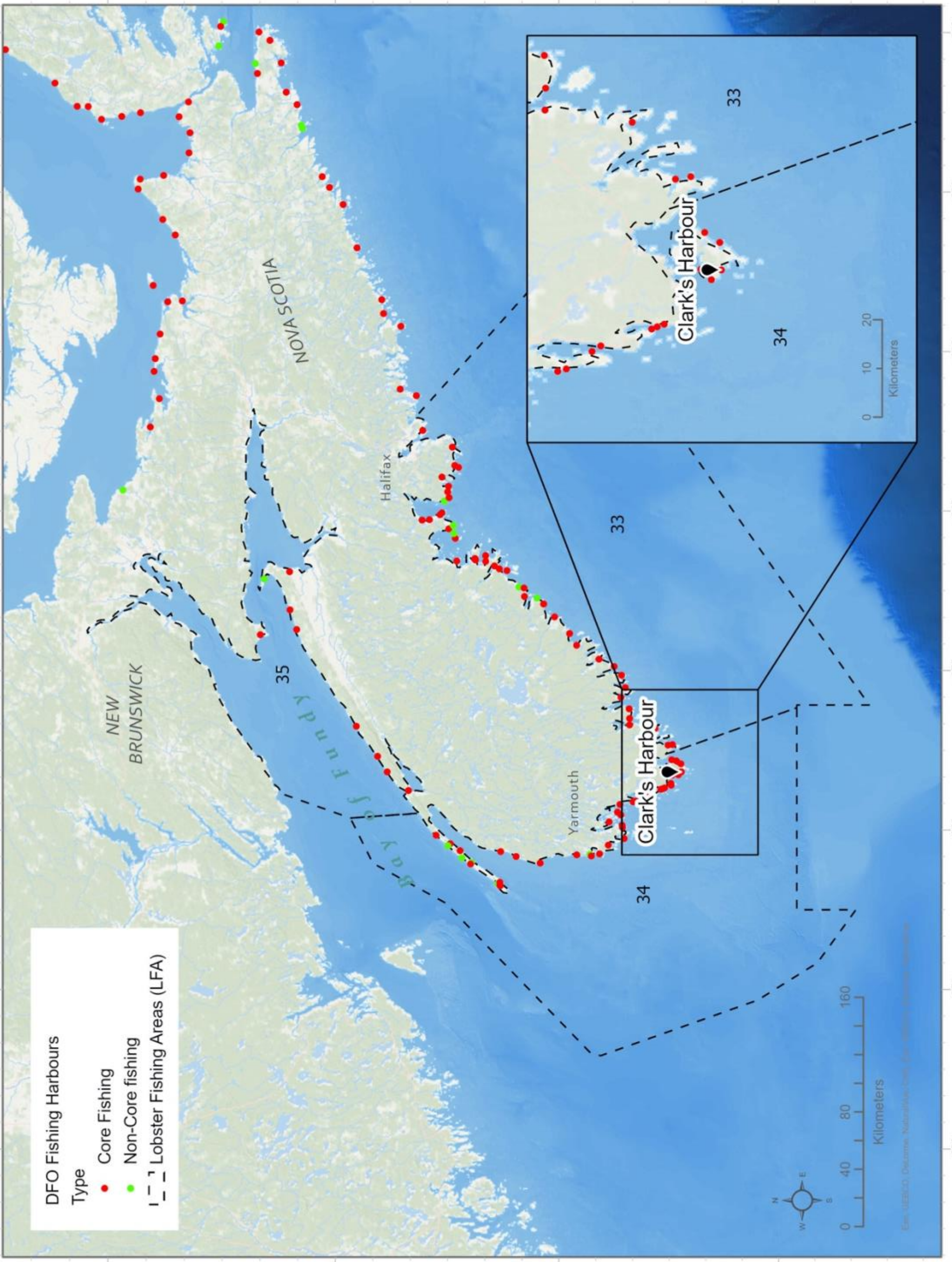
Tian, W.-M. (2008). Integrated method for the detection and location of underwater pipelines. *Applied Acoustics, 69*, 387–398.

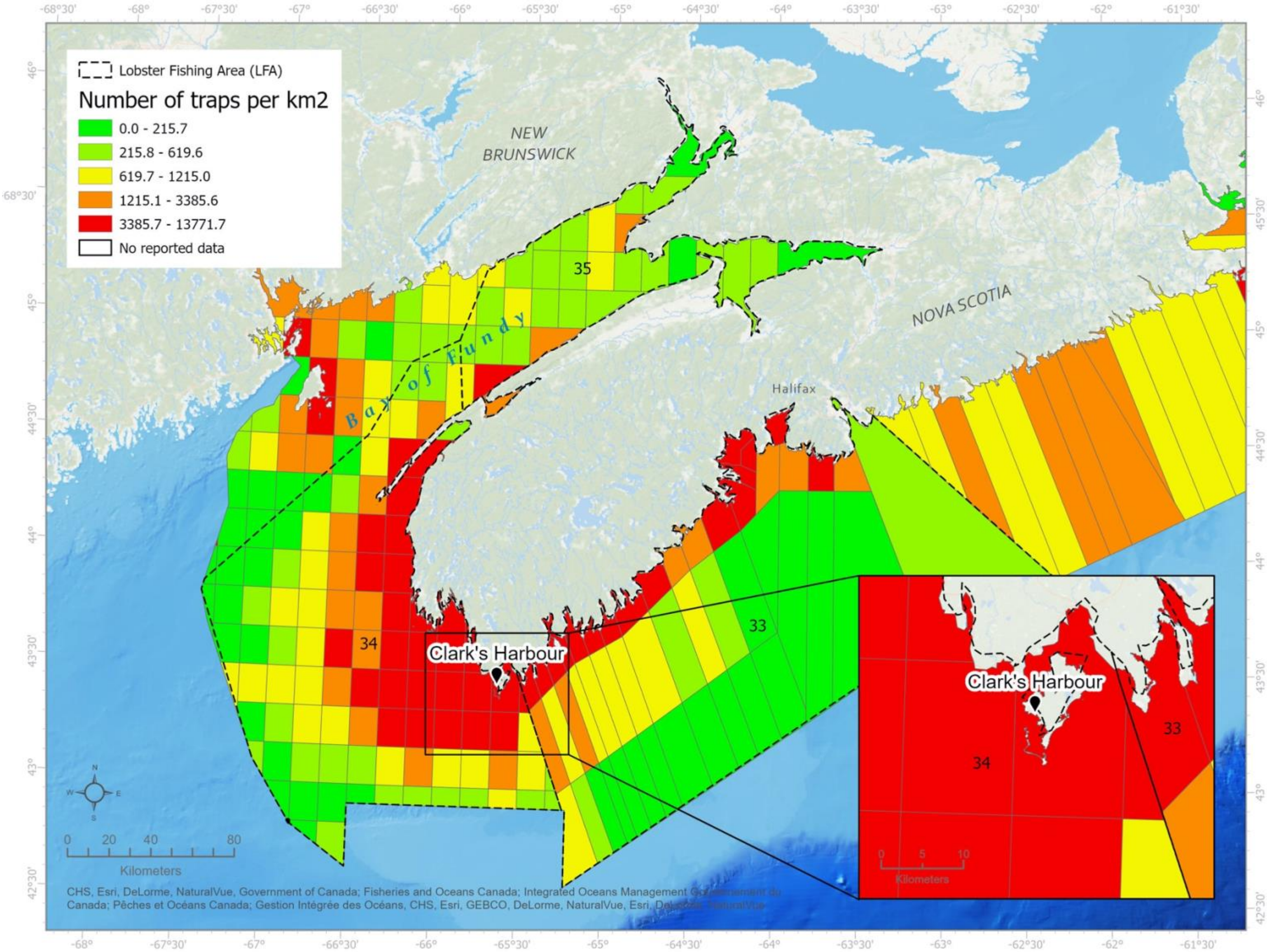
UNEP. (2014). *Annual Report.* United Nations, United Nations Environment Programme. United Nations Environment Programme.

Wang, Z., Lu, Y., Greenan, B., Brickman, D., & DeTracey, B. (2018). Bedford Institute of Oceanography North Atlantic Model . *BNAM: An eddy resolving North Atlantic Ocean model to support ocean monitoring., 327*. Can. Tech. Rep. Hydrogr. Ocean. Sci.

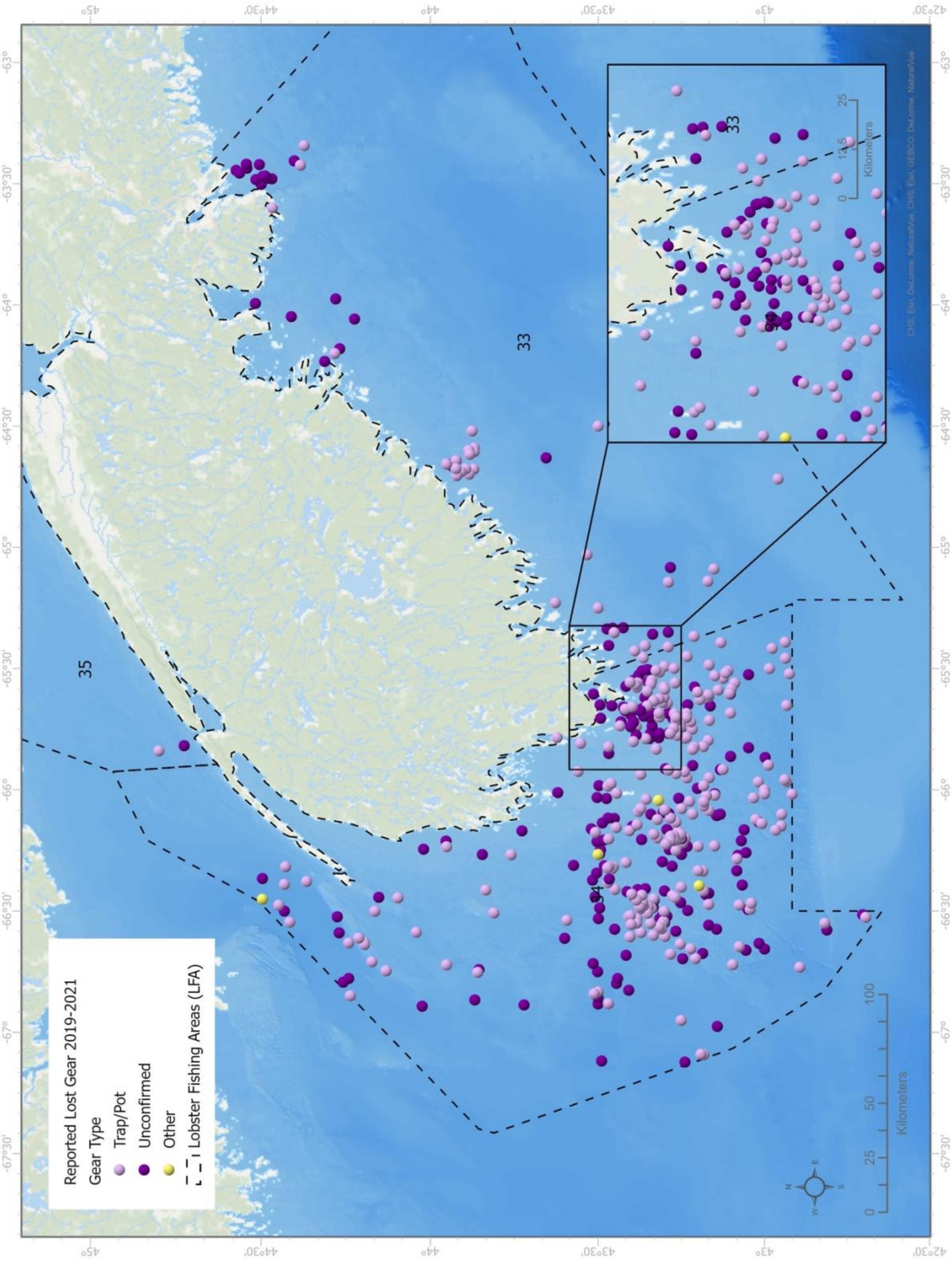
Yu, H., Li, Z., Li, D., & Shen, T. (2020). Bottom Detection Method of Side-Scan Sonar Image for AUV Missions. *Unmanned Autonomous Systems in Complex Environments, 2020*.

# Appendix A

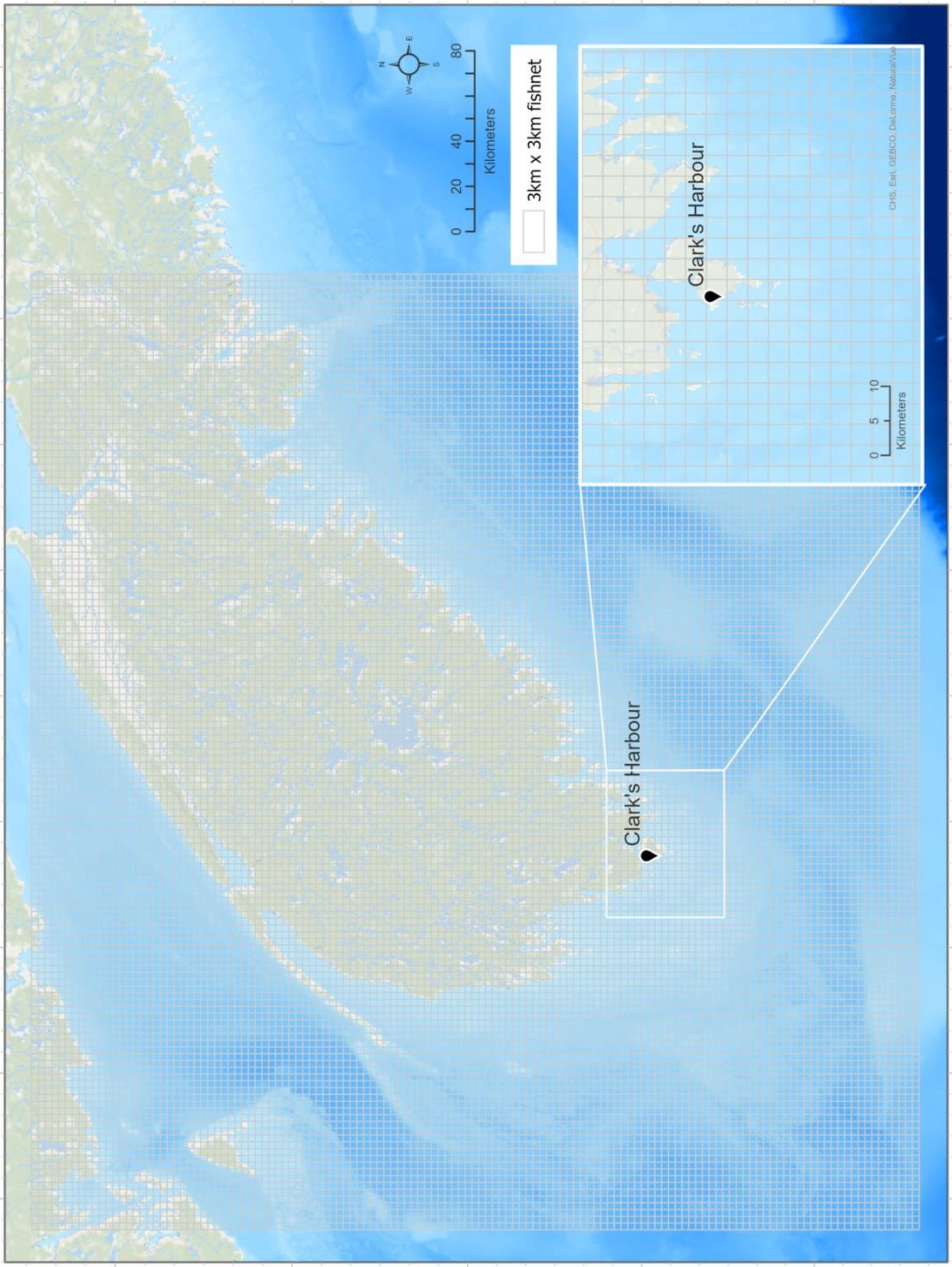

DFO Fishing Harbours
Type
Core Fishing
Non-Core fishing
Lobster Fishing Areas (LFA)
NOVA SCOTIA
NEW BRUNSWICK
Bay of Fundy
Halifax
Yarmouth
Clark's Harbour
Clark's Harbour
33
33
34
34
35
0
10
20
Kilometers
0
40
80
160
Kilometers
-61°
-62°
-63°
-64°
-65°
-66°
-67°
-68°
46°
45°
44°
43°



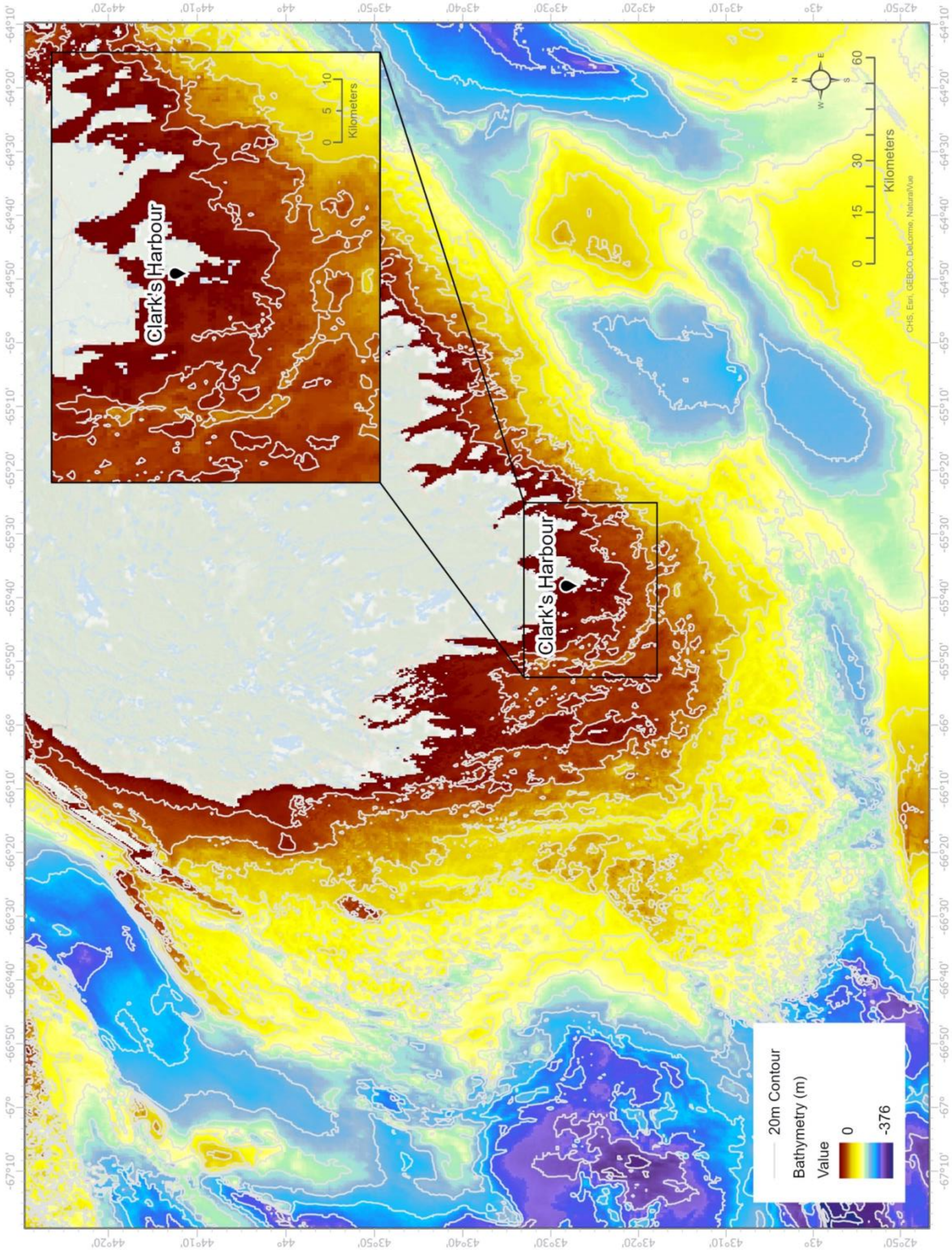
CHS, Esri, DeLorme, NaturalVue, Government of Canada; Fisheries and Oceans Canada; Integrated Oceans Management Gouvernement du Canada; Pêches et Océans Canada; Gestion Intégrée des Océans, CHS, Esri, GEBCO, DeLorme, NaturalVue, Esri, DeLorme, NaturalVue

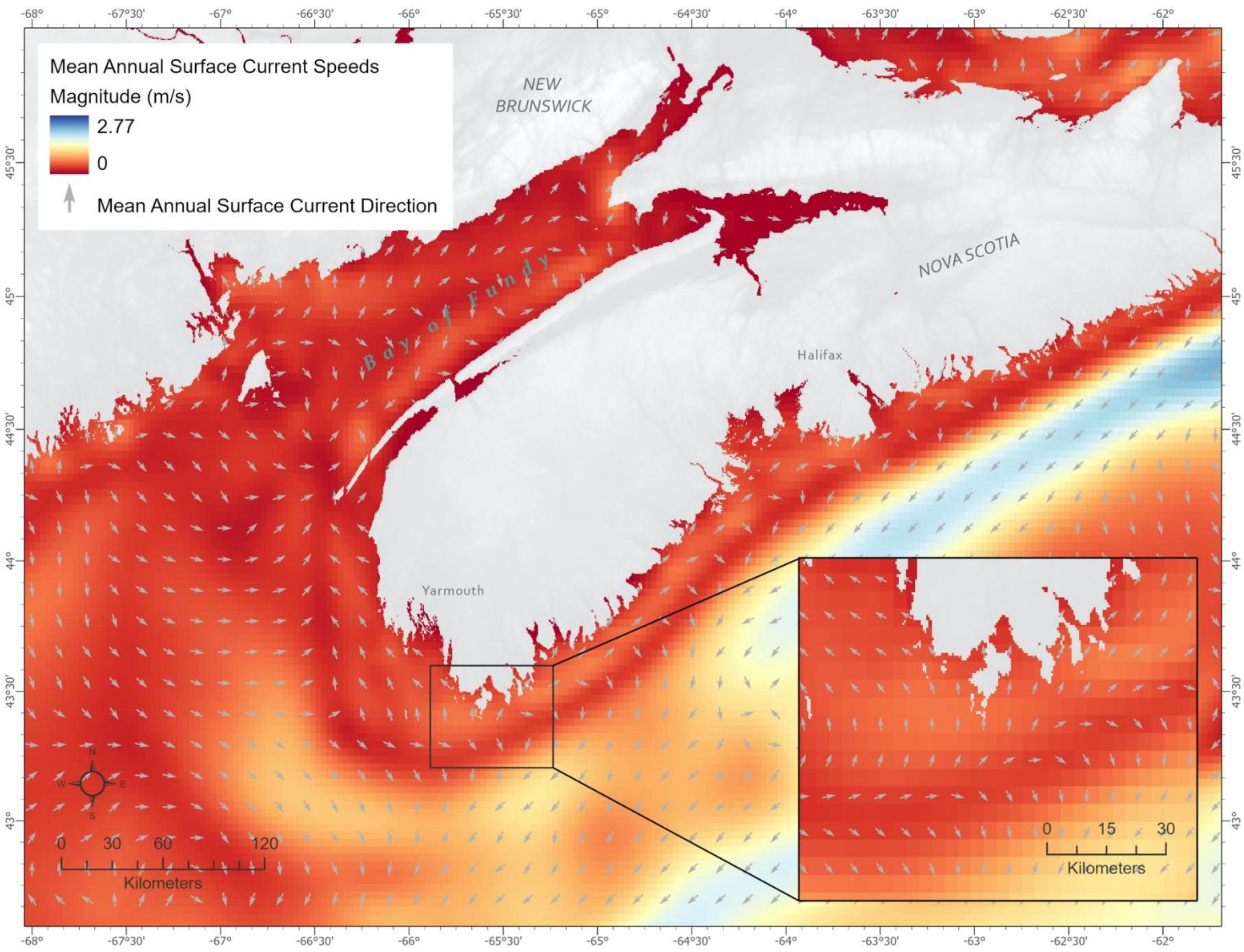

Reported Lost Gear 2019-2021
Gear Type
Trap/Pot
Unconfirmed
Other
Lobster Fishing Areas (LFA)
33
34
35
0
25
50
100
Kilometers
0
12.5
25
Kilometers
N
E
S
W
45°
44°30'
44°
43°30'
43°
42°30'
-63°
-63°30'
-64°
-64°30'
-65°
-65°30'
-66°
-66°30'
-67°
-67°30'
CHS, Esri, DeLorme, NaturalVue, CHS, Esri, GEBCO, DeLorme, NaturalVue

# Appendix B

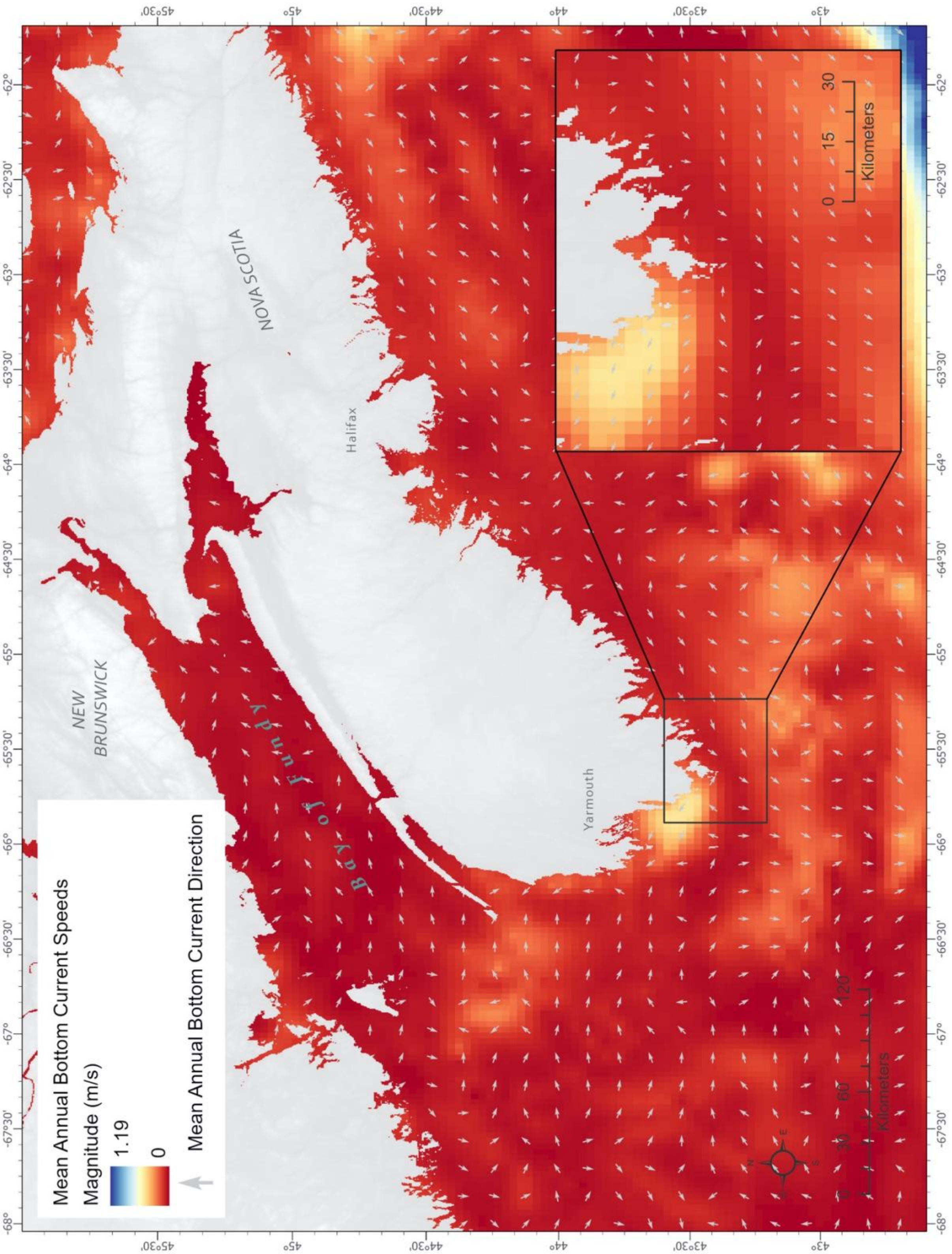

45°
44°30'
44°
43°30'
43°
-62°30'
-63°
-63°30'
-64°
-64°30'
-65°
-65°30'
-66°
-66°30'
-67°
N
E
S
W
0
20
40
80
Kilometers
3km x 3km fishnet
Clark's Harbour
Clark's Harbour
0
5
10
Kilometers
CHS, Esri, GEBCO, DeLorme, NaturalVue

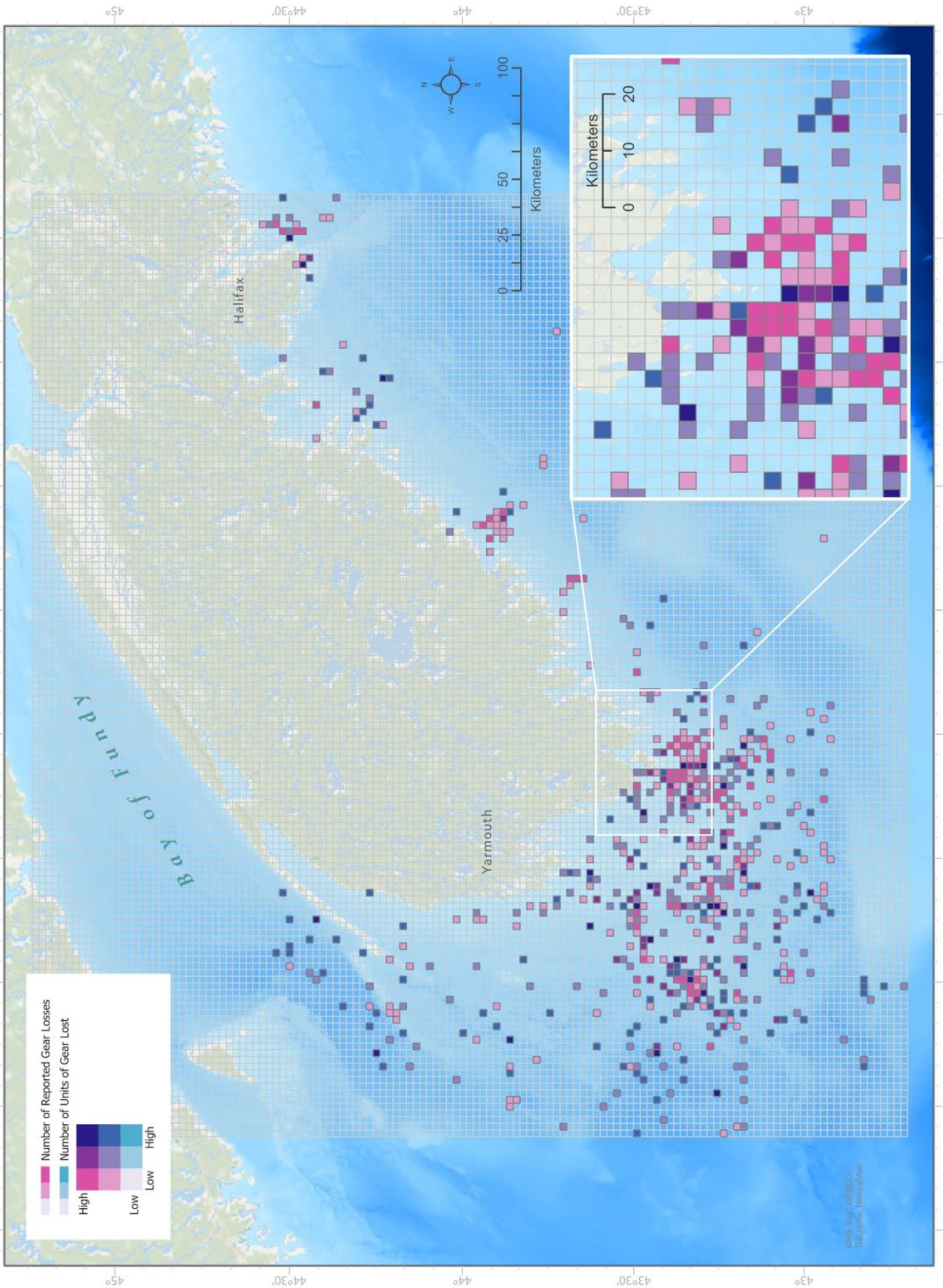
# Appendix C


Clark's Harbour
Clark's Harbour
0 5 10
Kilometers
0 15 30 60
Kilometers
N
E
S
W
CHS, Esri, GEBCO, DeLorme, NaturalVue
20m Contour
Bathymetry (m)
Value
0
-376
-64°10'
-64°20'
-64°30'
-64°40'
-64°50'
-65°
-65°10'
-65°20'
-65°30'
-65°40'
-65°50'
-66°
-66°10'
-66°20'
-66°30'
-66°40'
-66°50'
-67°
-67°10'
44°20'
44°10'
44°
43°50'
43°40'
43°30'
43°20'
43°10'
43°
42°50'

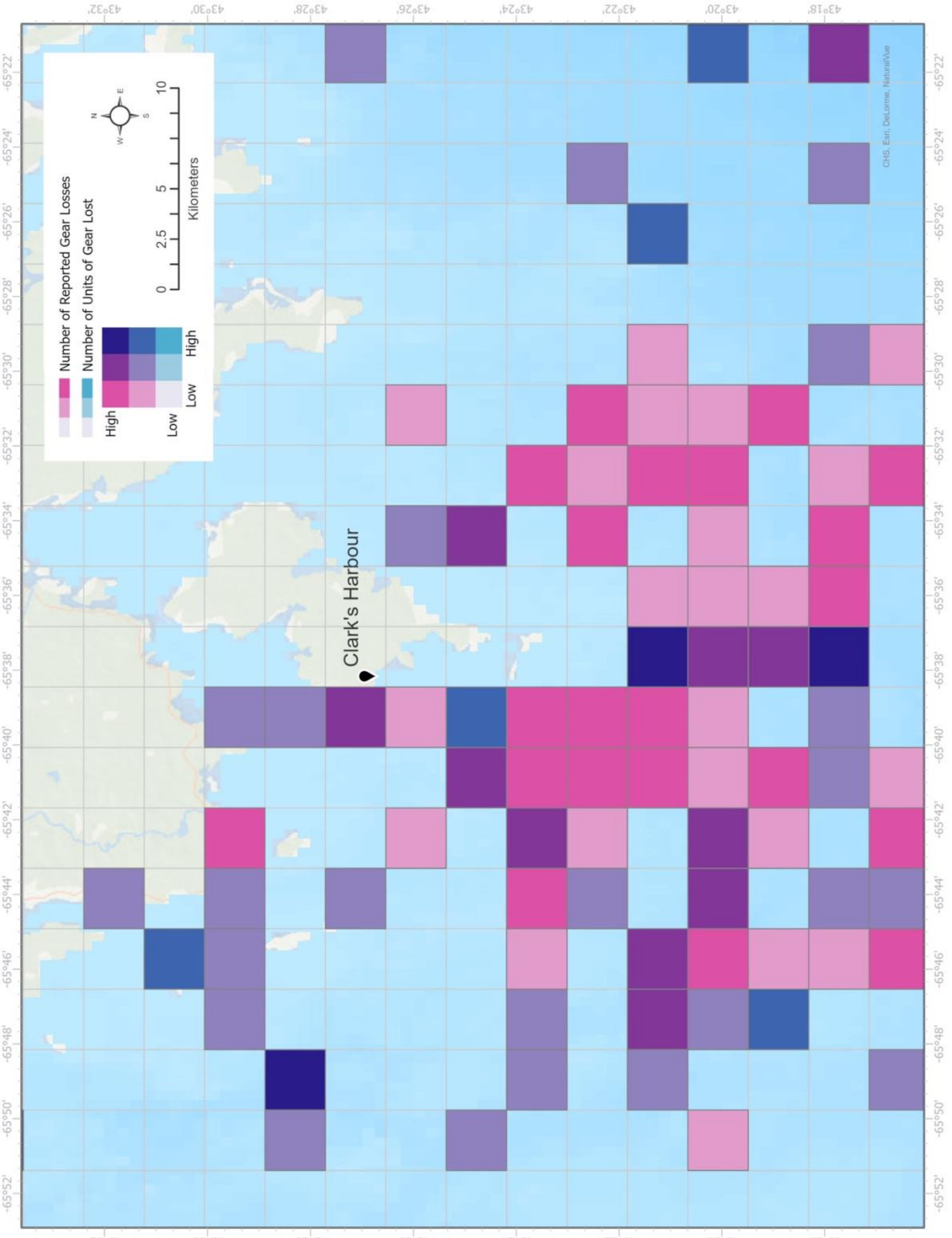


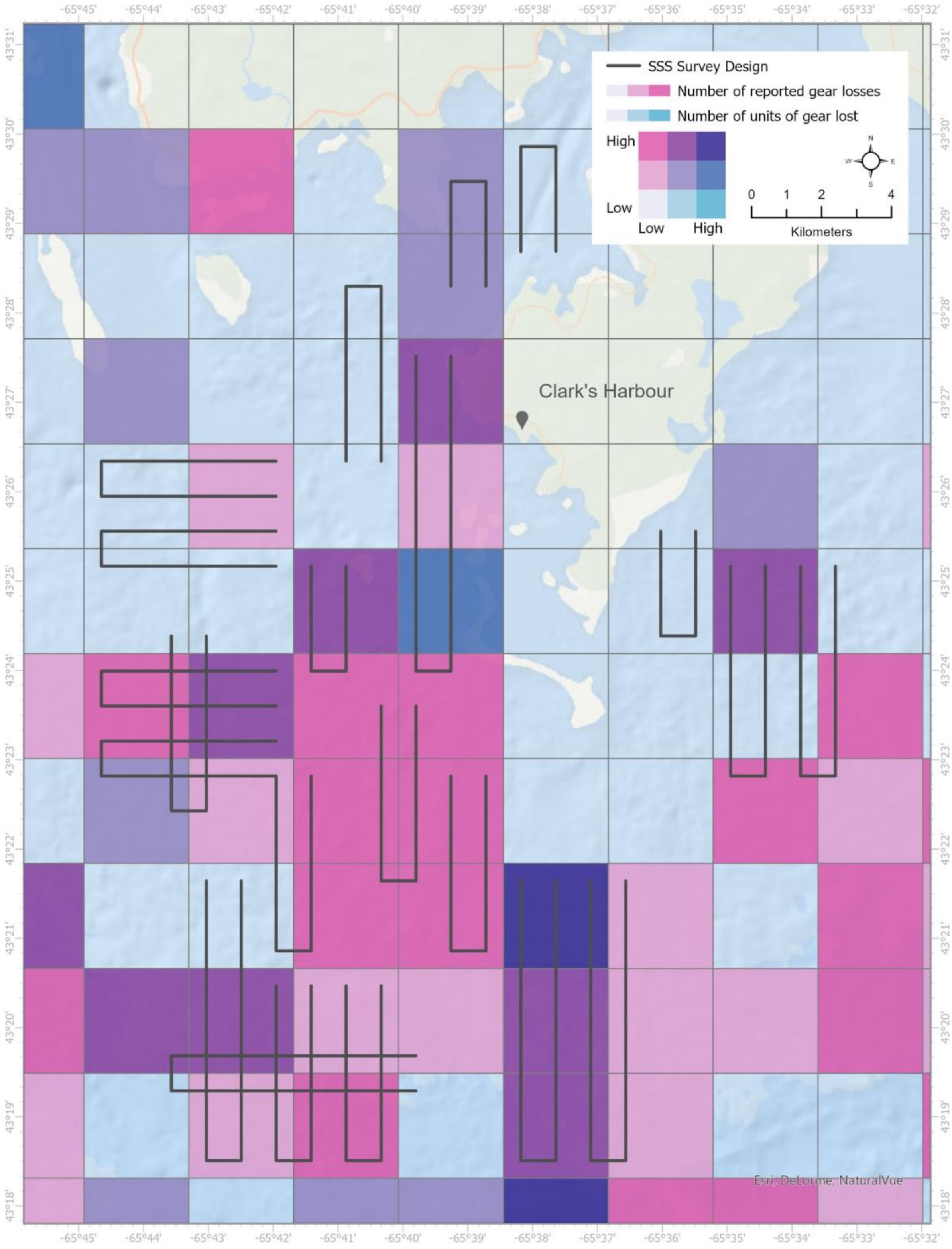
Mean Annual Surface Current Speeds
Magnitude (m/s)
2.77
0
Mean Annual Surface Current Direction
NEW BRUNSWICK
NOVA SCOTIA
Bay of Fundy
Halifax
Yarmouth
N
E
S
W
0
30
60
120
Kilometers
0
15
30
Kilometers
-68°
-67°30'
-67°
-66°30'
-66°
-65°30'
-65°
-64°30'
-64°
-63°30'
-63°
-62°30'
-62°
45°30'
45°
44°30'
44°
43°30'
43°


Mean Annual Bottom Current Speeds
Magnitude (m/s)
1.19
0
Mean Annual Bottom Current Direction
NEW BRUNSWICK
NOVA SCOTIA
Bay of Fundy
Halifax
Yarmouth
0
30
60
120
Kilometers
0
15
30
Kilometers
-68°
-67°30'
-67°
-66°30'
-66°
-65°30'
-65°
-64°30'
-64°
-63°30'
-63°
-62°30'
-62°
45°30'
45°
44°30'
44°
43°30'
43°



45°
44°30'
44°
43°30'
43°
-63°
-63°30'
-64°
-64°30'
-65°
-65°30'
-66°
-66°30'
-67°
-67°30'
Halifax
Yarmouth
Bay of Fundy
0
25
50
100
Kilometers
N
E
S
W
Kilometers
0
10
20
Number of Reported Gear Losses
Number of Units of Gear Lost
High
Low
Low
High
CHS, Esri, GEBCO, DeLorme, NaturalVue


Number of Reported Gear Losses
Number of Units of Gear Lost
High
Low
Low
High
0
2.5
5
10
Kilometers
N
E
S
W
Clark's Harbour
CHS, Esri, DeLorme, NaturalVue
-65°22'
-65°24'
-65°26'
-65°28'
-65°30'
-65°32'
-65°34'
-65°36'
-65°38'
-65°40'
-65°42'
-65°44'
-65°46'
-65°48'
-65°50'
-65°52'
43°32'
43°30'
43°28'
43°26'
43°24'
43°22'
43°20'
43°18'


-65°45'
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-65°39'
-65°38'
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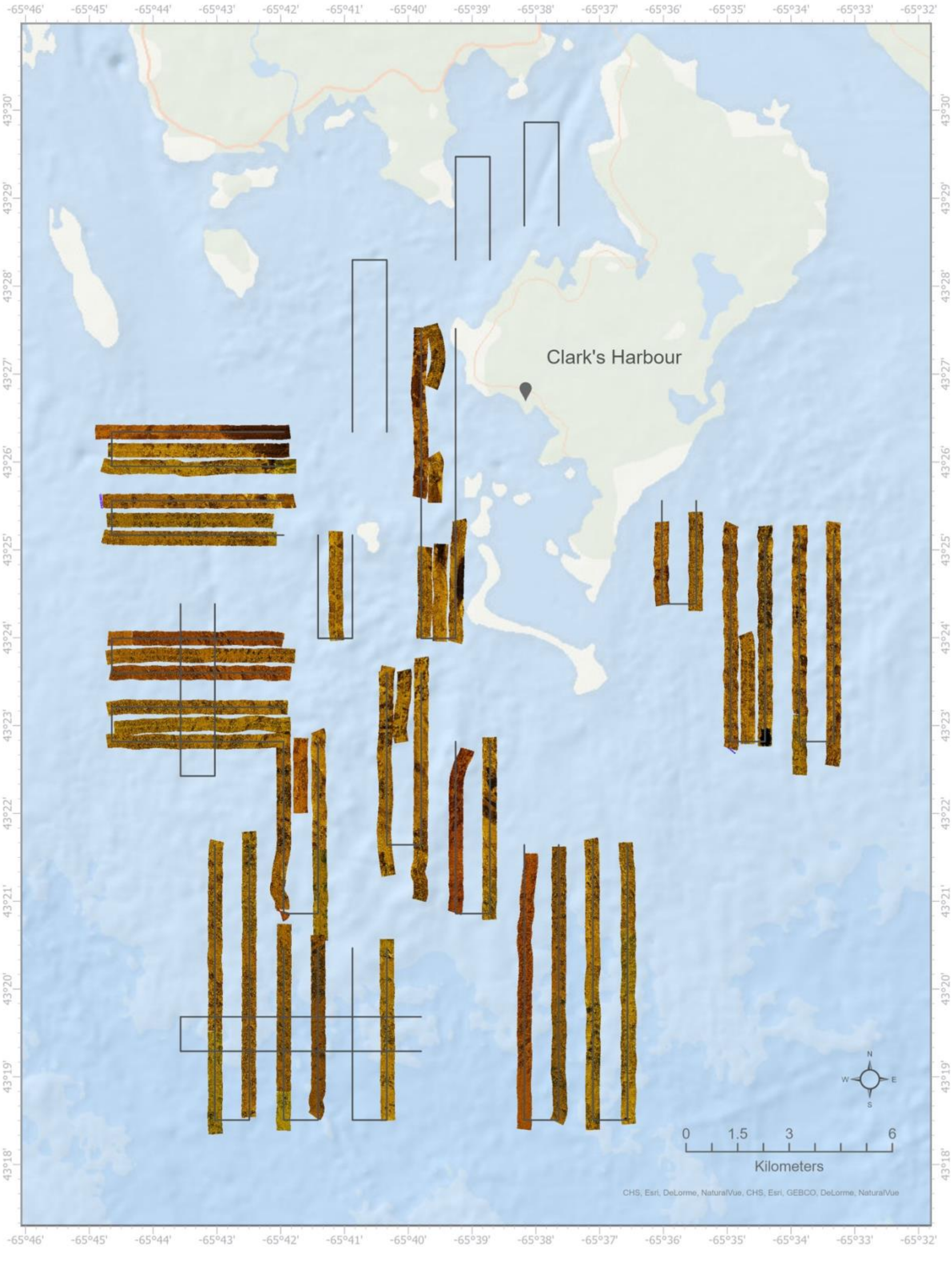
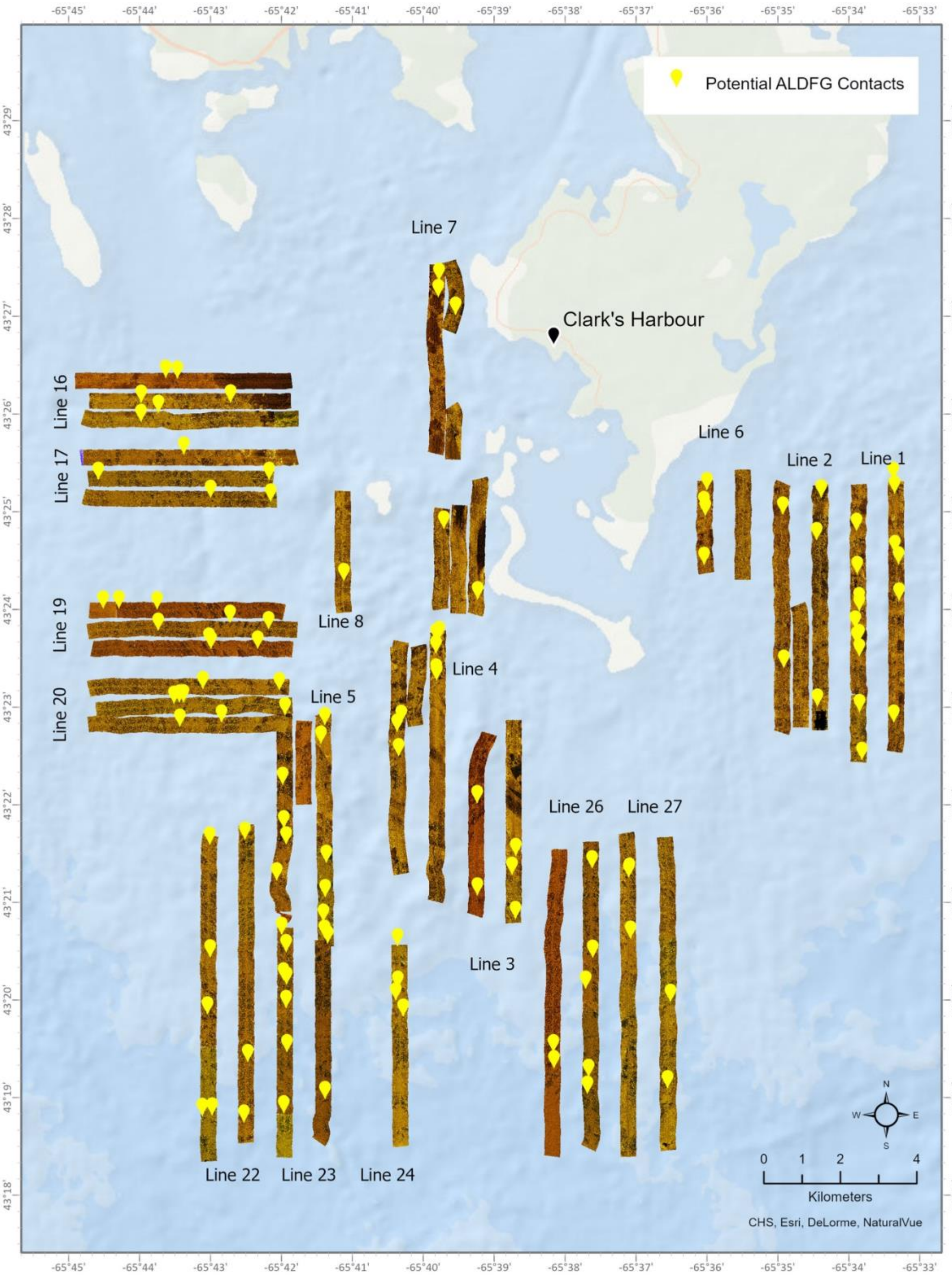
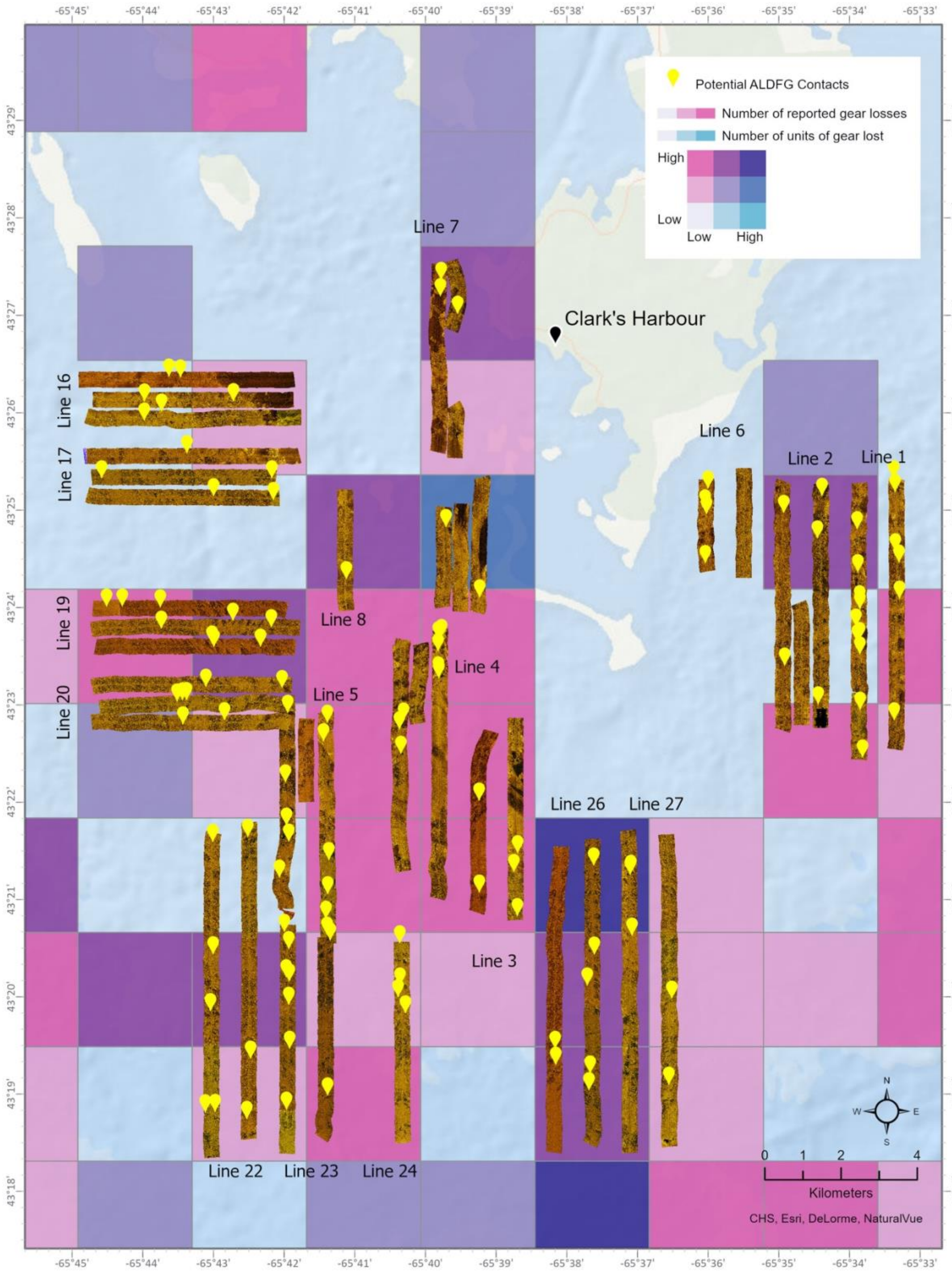
-65°36'
-65°35'
-65°34'
-65°33'
-65°32'
43°31'
43°30'
43°29'
43°28'
43°27'
43°26'
43°25'
43°24'
43°23'
43°22'
43°21'
43°20'
43°19'
43°18'
SSS Survey Design
Number of reported gear losses
Number of units of gear lost
High
Low
Low
High
N
W
E
S
0
1
2
4
Kilometers
Clark's Harbour
Esri, DeLorme, NaturalVue



CHS, Esri, DeLorme, NaturalVue, CHS, Esri, GEBCO, DeLorme, NaturalVue



Potential ALDFG Contacts
Clark's Harbour
Line 1
Line 2
Line 3
Line 4
Line 5
Line 6
Line 7
Line 8
Line 16
Line 17
Line 19
Line 20
Line 22
Line 23
Line 24
Line 26
Line 27
N
S
E
W
0
1
2
4
Kilometers
CHS, Esri, DeLorme, NaturalVue
-65°45'
-65°44'
-65°43'
-65°42'
-65°41'
-65°40'
-65°39'
-65°38'
-65°37'
-65°36'
-65°35'
-65°34'
-65°33'
43°29'
43°28'
43°27'
43°26'
43°25'
43°24'
43°23'
43°22'
43°21'
43°20'
43°19'
43°18'


Potential ALDFG Contacts
Number of reported gear losses
Number of units of gear lost
High
Low
Low
High
Clark's Harbour
Line 1
Line 2
Line 3
Line 4
Line 5
Line 6
Line 7
Line 8
Line 16
Line 17
Line 19
Line 20
Line 22
Line 23
Line 24
Line 26
Line 27
N
S
E
W
0
1
2
4
Kilometers
CHS, Esri, DeLorme, NaturalVue
-65°45'
-65°44'
-65°43'
-65°42'
-65°41'
-65°40'
-65°39'
-65°38'
-65°37'
-65°36'
-65°35'
-65°34'
-65°33'
43°29'
43°28'
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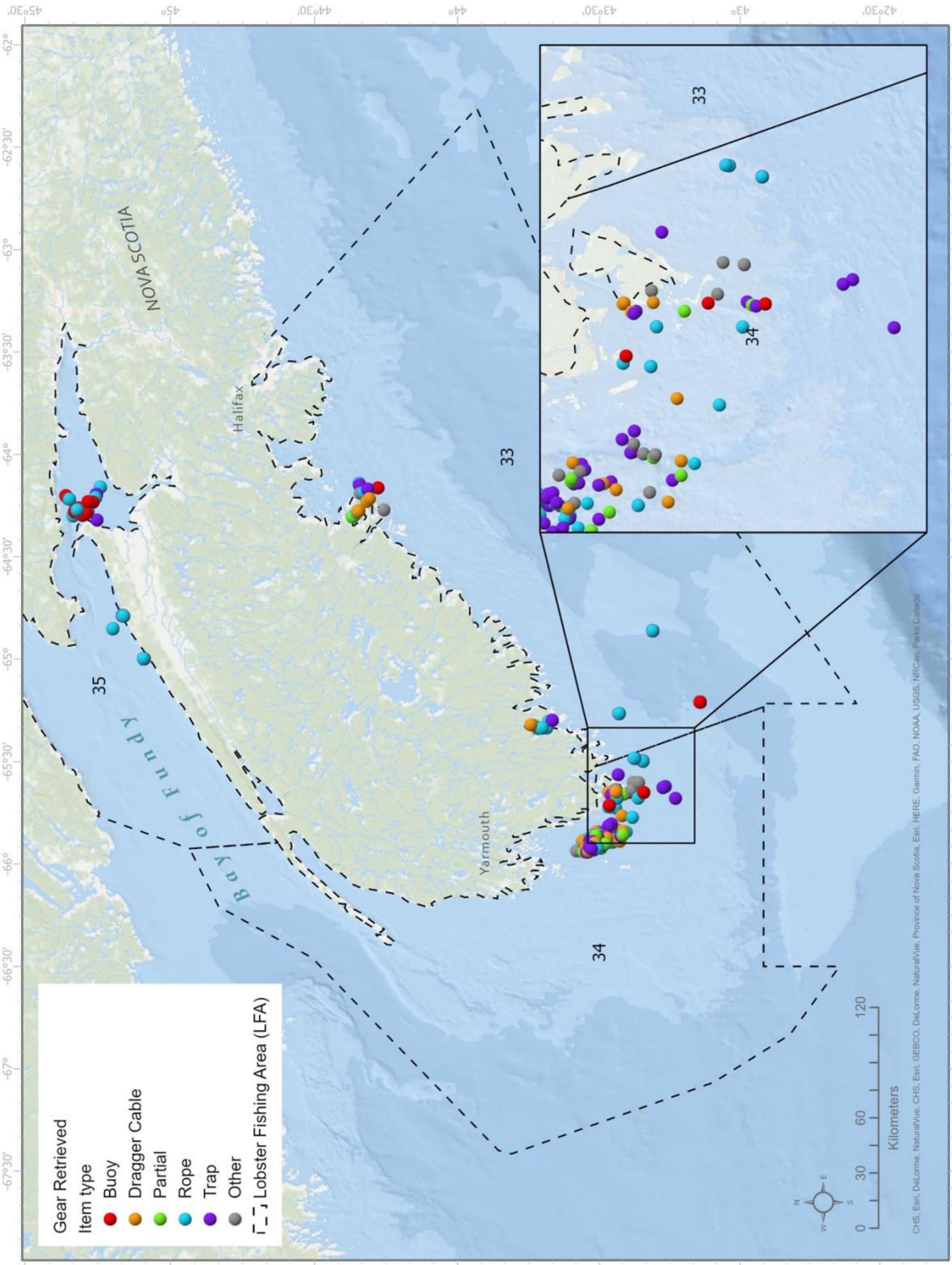
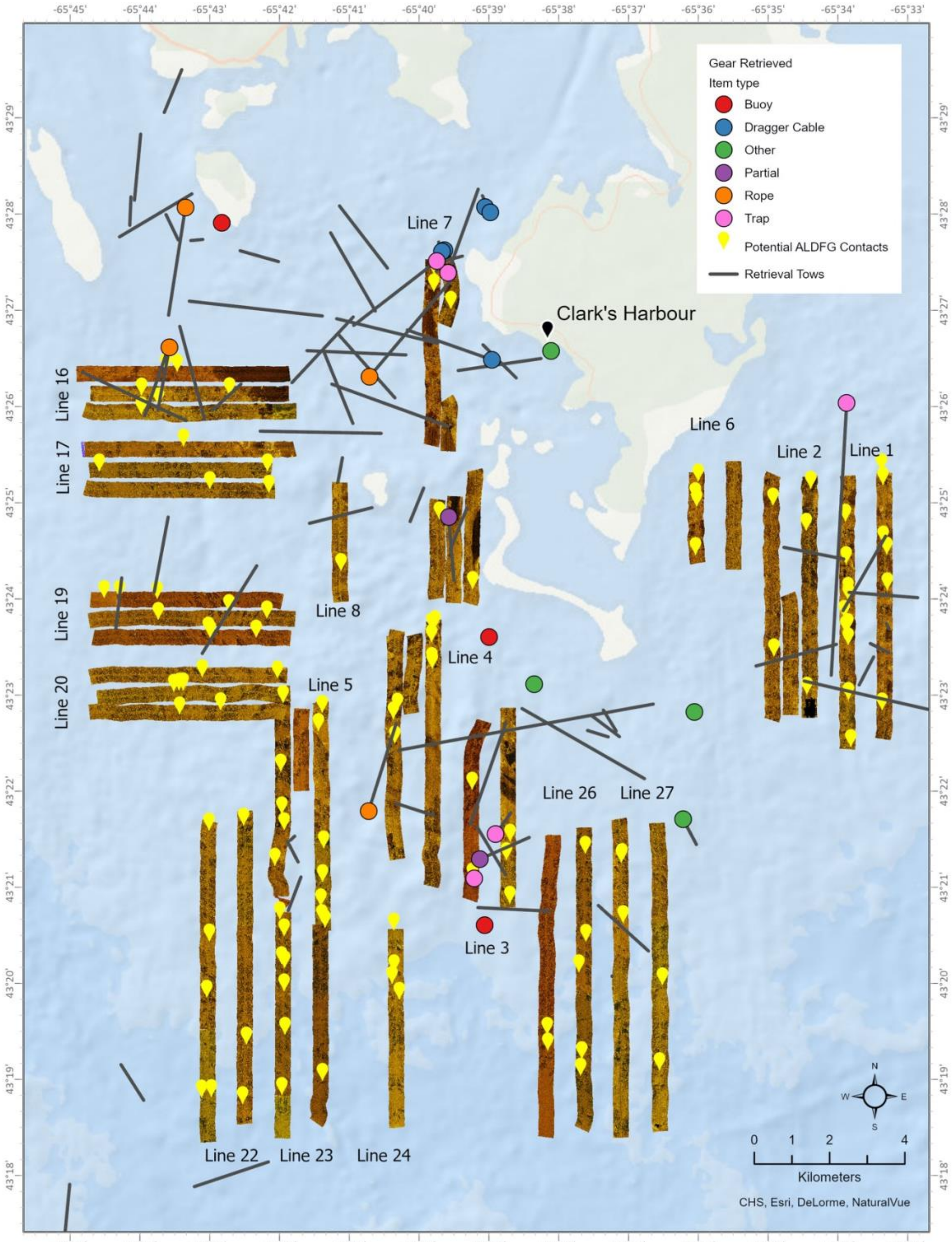
43°19'
43°18'



CHS, Esri, DeLorme, NaturalVue, CHS, Esri, GEBCO, DeLorme, NaturalVue, Province of Nova Scotia, Esri, HERE, Garmin, FAO, NOAA, USGS, NRCan, Parks Canada


-65°45'
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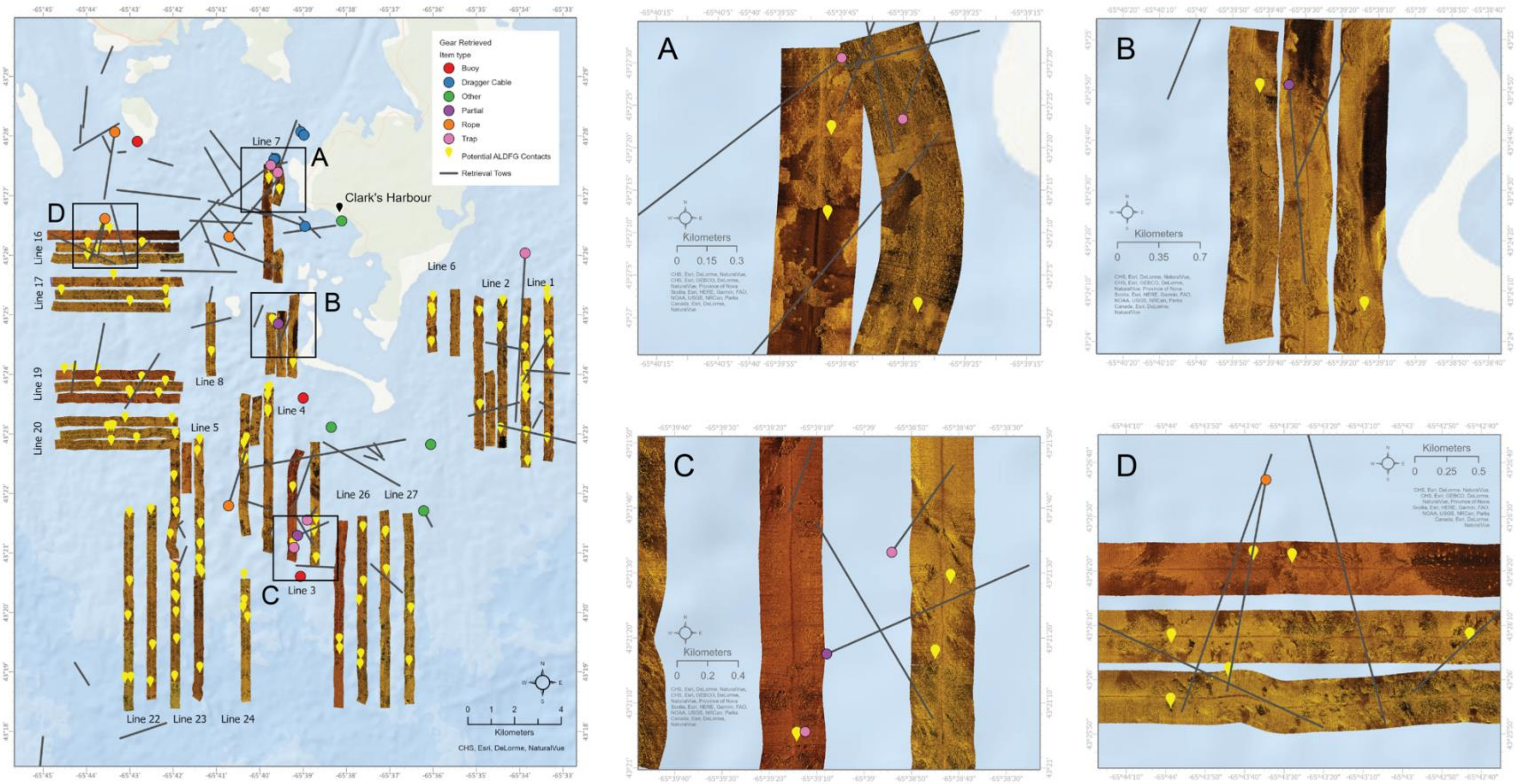
-65°33'
43°29'
43°28'
43°27'
43°26'
43°25'
43°24'
43°23'
43°22'
43°21'
43°20'
43°19'
43°18'
Gear Retrieved
Item type
Buoy
Dragger Cable
Other
Partial
Rope
Trap
Potential ALDFG Contacts
Retrieval Tows
Line 7
Clark's Harbour
Line 16
Line 17
Line 6
Line 2
Line 1
Line 8
Line 19
Line 4
Line 20
Line 5
Line 26
Line 27
Line 3
Line 22
Line 23
Line 24
N
W
E
S
0
1
2
4
Kilometers
CHS, Esri, DeLorme, NaturalVue


Gear Retrieved
Item type
Buoy
Dragger Cable
Other
Partial
Rope
Trap
Potential ALDFG Contacts
Retrieval Tows
Clark's Harbour
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Line 2
Line 3
Line 4
Line 5
Line 6
Line 7
Line 8
Line 16
Line 17
Line 19
Line 20
Line 22
Line 23
Line 24
Line 26
Line 27
A
B
C
D
Kilometers
0 1 2 4
CHS, Esri, DeLorme, NaturalVue
Kilometers
0 0.15 0.3
Kilometers
0 0.35 0.7
Kilometers
0 0.2 0.4
Kilometers
0 0.25 0.5